



## INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification <sup>6</sup> : <b>G06F 9/46, 17/60</b>		A1	(11) International Publication Number: <b>WO 99/17194</b> (43) International Publication Date: <b>8 April 1999 (08.04.99)</b>		
(21) International Application Number: <b>PCT/GB98/02944</b>	(22) International Filing Date: <b>1 October 1998 (01.10.98)</b>	(81) Designated States: AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GE, GH, GM, HR, HU, ID, IL, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, UA, UG, US, UZ, VN, YU, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).			
(30) Priority Data: <b>97307745.6</b> 1 October 1997 (01.10.97) EP					
(71) Applicant (for all designated States except US): BRITISH TELECOMMUNICATIONS PUBLIC LIMITED COMPANY [GB/GB]; 81 Newgate Street, London EC1A 7AJ (GB).					
(72) Inventors; and (75) Inventors/Applicants (for US only): PUROHIT, Bharat [GB/GB]; 23 Potter Street, Northwood Hills, Middlesex HA6 1QJ (GB). SHEPHERDSON, John, William [GB/GB]; 4 Abbey Road, Sudbury, Suffolk CO10 6LA (GB). JUDGE, Donald [GB/GB]; 78 Leopold Road, Ipswich, Suffolk IP4 4RN (GB). ODGERS, Brian, Robert [GB/GB]; 15 Kingsway Grove, Lurgan, County Armagh BT66 7TE (GB).					
(74) Agents: MUSKER, David, Charles et al.; R.G.C. Jenkins & Co., 26 Caxton Street, London SW1H 0RJ (GB).					
(54) Title: RESOURCE MANAGEMENT SYSTEM		Published With international search report. Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.			
(57) Abstract					
<p>A resource handling system (120) has an intelligent software agent-based layer which provides a quasi-centralised control. The system has an interface to a user community and receives resource requests (115). There are multiple agents which negotiate to provide a response. The response can be substantially in real-time, rather than via a planning and scheduling capability, while there is also management of over- and under-bidding by the agents.</p>					

**FOR THE PURPOSES OF INFORMATION ONLY**

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AL	Albania	ES	Spain	LS	Lesotho	SI	Slovenia
AM	Armenia	FI	Finland	LT	Lithuania	SK	Slovakia
AT	Austria	FR	France	LU	Luxembourg	SN	Senegal
AU	Australia	GA	Gabon	LV	Latvia	SZ	Swaziland
AZ	Azerbaijan	GB	United Kingdom	MC	Monaco	TD	Chad
BA	Bosnia and Herzegovina	GE	Georgia	MD	Republic of Moldova	TG	Togo
BB	Barbados	GH	Ghana	MG	Madagascar	TJ	Tajikistan
BE	Belgium	GN	Guinea	MK	The former Yugoslav Republic of Macedonia	TM	Turkmenistan
BF	Burkina Faso	GR	Greece	ML	Mali	TR	Turkey
BG	Bulgaria	HU	Hungary	MN	Mongolia	TT	Trinidad and Tobago
BJ	Benin	IE	Ireland	MR	Mauritania	UA	Ukraine
BR	Brazil	IL	Israel	MW	Malawi	UG	Uganda
BY	Belarus	IS	Iceland	MX	Mexico	US	United States of America
CA	Canada	IT	Italy	NE	Niger	UZ	Uzbekistan
CF	Central African Republic	JP	Japan	NL	Netherlands	VN	Viet Nam
CG	Congo	KR	Kenya	NO	Norway	YU	Yugoslavia
CH	Switzerland	KG	Kyrgyzstan	NZ	New Zealand	ZW	Zimbabwe
CI	Côte d'Ivoire	KP	Democratic People's Republic of Korea	PL	Poland		
CM	Cameroon	KR	Republic of Korea	PT	Portugal		
CN	China	KZ	Kazakhstan	RO	Romania		
CU	Cuba	LC	Saint Lucia	RU	Russian Federation		
CZ	Czech Republic	LI	Liechtenstein	SD	Sudan		
DE	Germany	LK	Sri Lanka	SE	Sweden		
DK	Denmark	LR	Liberia	SG	Singapore		
EE	Estonia						

## RESOURCE MANAGEMENT SYSTEM

The present invention relates to process management and particularly to resource allocation in carrying out processes.

5 Resource allocation can often present a complex problem in an environment in which many tasks need to be carried out by various resources and with varying levels of priority. In practice, this is further complicated by changes in the situation, such as incoming tasks of high urgency and equipment failure.

There are systems already known for resource allocation. For instance, 10 an example of resource allocation is the automation of a business process. Documents, information or tasks can be passed from one resource to another for action according to a set of procedural rules. There is a description of such a system, published by the Workflow Management Coalition under the title "Workflow Reference Model Specification" on the Internet at the Universal 15 Resource Location (URL) <http://www.aiim.ed.ac.uk:80/WfMC> (now <http://www.aiim.org/wfmc>). The Coalition has proposed a framework for the establishment of workflow standards. This framework includes five categories of interoperability and communication standards that will allow multiple workflow products to exist and interoperate within a user's environment. The Coalition has 20 also published a white paper entitled "The Work of the Coalition".

Workflow in this context is relevant to such areas as image management systems, document management systems, relational or object database systems and electronic mail systems.

One approach to automating workflow (specifically, job scheduling) is 25 disclosed in GB 2194086, in which computer calculates scheduling for completing projects with limited resources (e.g. people).

The article "Resource Management in Large Distributed Systems", 30 Goscinski A et al, Operating systems Review (SIGOPS), vol. 24, No. 4, 1 October 1990, pages 7-25, discloses sharing computing resources (for example printers and computation) by using a resource management centre which negotiates with a local network. It does not discuss workflow.

The article "Using Intelligent Agents to Manage Business Processes", Jennings et al, Proc First International Conference on the Practice Application of

Intelligent Agents and Multi Agent Technology (PAAM 96), London, 1996, pages 345-360, discusses the use of negotiating agents to manage workflow. The agents comprise, for example, a management module which negotiates for services which are needed, and other modules (which may be at a hierarchically lower level) which can provide services through service execution modules, and which negotiate with the management module.

The results of the negotiation is to set up a long term service life cycle agreement (SLA) constituting an agreement to do a certain amount of work per unit of time on agreed terms. These may be re-negotiated.

10 The foregoing are generally concerned with work flow management, which is a process of allocating streams of work between different resources; in other words, allocating rates at which work is to be done. Thus, reallocation of the resources is only required where the rates at which work is to be done are changed. Examples are call handling in a call service centre; correspondence 15 handling in a correspondence service centre; manufacturing and assembly processes and so on.

General discussion of the application of agents to network management is disclosed in "Applying the Agent Paradigm to Network Management", Davidson et al, BTTJ Vol. 16, No. 3, July 1998.

20 According to embodiments of the present invention there is provided a resource allocation system comprising computing means for executing: at least one first computer program module for determining an allocation matching one or more of a plurality of resource supplies to a resource requirement; at least two second computer program module for monitoring the state of a corresponding one 25 of said resource supplies and for communicating with said first program module.

It will be understood that the invention is also applicable to similar processes; for example, to the distribution of telecommunications bit streams between several different channels having varying channel capacities. For example, a broad bandwidth bit stream may be split between several ISDN 30 channels.

WO 97/37501 describes a telecommunications systems with agent-negotiated routing.

More generally, however, the extension of the principles of the present invention to resource allocation systems in which individual items of work are distributed (rather than rates at which work is to be done) is not excluded.

A particularly convenient format for providing the software modules is in 5 the form of software agents.

This can be provided as an arrangement referred to herein as "Agent Enhanced Workflow" (AEW). Agent Enhanced Workflow is a novel technique whereby a community of intelligent, distributed, autonomous software agents is used to improve the management of business processes currently under the 10 control of Workflow Management Systems. Agent Enhanced Workflow can specifically address shortcomings in such systems by adding a layer of software agents to the Workflow Management System architecture. These Workflow Agents can collaborate to perform real-time exception handling and/or co-ordinate the distribution of work items. This is to be distinguished from "Agent Based 15 Workflow", which replaces such existing architecture as in the prior art cited above.

The layer of software agents can be added retrospectively to an existing workflow management system or can be designed into a new workflow management system as an integral part.

20 Software agent technology has developed over the past few years in several different fields. A software agent is a computer program which acts as an agent for an entity such as a user, a piece of equipment or a business. The software agent usually holds data in relation to the entity it represents, has a set of constraints or conditions to determine its behaviour and, most importantly, is 25 provided with decision making software for making decisions on behalf of the entity within or as a result of the constraints and conditions. Agents are generally acting within a system and the decisions an agent makes can result in activity by the system. In control software systems, those decisions result in control activity, such as initiating connection set-up in a communications network 30 controlled by the system.

An agent acting within a system will also generally hold data about the system so that it can operate in context.

In a distributed environment, many such agents may co-operate to co-ordinate and perform the control activities. Typically, such agents form an agent layer, with each agent interfacing with one or more external systems (the domain layer) which they control, monitor or manage.

5 An agent-based system can be very complex since the interactions between the agents, the decision-making processes of individual agents and the interactions between agents and the external systems they control, need to be taken into account.

Different types of agent-based systems are described in several published 10 papers, such as those published in the proceedings of the First and Second International Conferences on the Practical Application of Intelligent Agents and Multi-Agent Technology. These are published by the Practical Application Company Ltd., Blackpool, Lancashire, in 1996 and 1997 respectively. A general comprehensive review of agent-based technology is given by Hyacinth S. Nwana, 15 "Software Agents: An Overview" in the *Knowledge Engineering Review* journal, Vol. 11, No. 3, pages 205-244.

Returning to AEW, an agent layer in a workflow management system can in particular overcome the inability of a workflow management system (WfMS) to cope with dynamic changes in resource levels and task availability. Similarly the 20 Workflow Agents can co-ordinate overall resource levels, bringing individual resources on and off-line as required to accommodate peaks and troughs in the incoming workload.

A workflow management system for a correspondence handling centre (CHC), according to an embodiment of the present invention, will now be 25 described, by way of example only, with reference to the accompanying Figures in which:

Figure 1 shows the overall organisation of components of the correspondence handling centre, together with its interfaces to a user community;

Figure 2 shows an overview of a process definition for the CHC;

30 Figure 3 shows the relationship between logical components of the workflow management system for the CHC;

Figure 4 shows a schematic view of the architecture of a workflow management system agent;

Figure 5 shows schematically the technological components of the CHC and the agent-based workflow management system;

Figure 6 shows schematically a protocol for negotiation between the agents of the workflow management system;

5 Figure 7 shows a price profile for use in the collaborative processes of the CHC agents;

Figures 8, 9 and 10 show steady state and negotiating phases of interactions between agents of the CHC;

Figure 11 is a block diagram showing the arrangement of computers on 10 which the embodiment is implemented;

Figure 12 (comprising Figures 12a-12d) is a flow diagram showing schematically the operation of a central administration agent; and

Figure 13 is a flow diagram showing schematically the process of 15 operation of a work processing centre agent of the embodiment.

15

#### FIRST EMBODIMENT

#### GLOSSARY

20 AEW: Agent Enhanced Workflow

CA : Central Administration

CAA : Central Administration Agent

CBR : Case Based Reasoning

CHC : Correspondence Handling Centre

25 SLA : Service Level Agreement

WAPI : Workflow APIs and Interchange Formats

WfMS or WMS : Workflow Management System

WPC : Work Processing Centre

WPCA : Work Processing Centre Agent

30 WMC : Work Management Centre (CA plus one or more WPCs)

WMCA : CA Agent(s) plus WPC Agents

**DEFINITIONS**

For the following and other definitions see 'Terminology & Glossary', Workflow Management Coalition (MFMC-TC01011), June 1996, 2.0.

5

Broadcast (message) : sent to all WPC Agents associated with a given CA Agent

Cost: a measure of the difficulty of achieving a particular objective

Delta: a vector quantity representing some change to the parameters of one or more of the work item categories processed by the Workflow

10 Management System

Narrowcast (message): sent to a subset of the WPC Agents associated with a given CA Agent

Normal capacity of WP : the maximum rate of work which a WPC can achieve, without recourse to additional, short-term staffing arrangements

15 N-way routing: synonymous with 'Parallel Routing', 'Parallel workflow processing' and 'Concurrent Processing'. "A segment of a process instance under enactment by a workflow management system, where two or more activity instances are executing in parallel within the workflow, giving rise to multiple threads of control"

20 Price: the monetary value (in pounds and pence or some other suitable unit) offered/charged for delivery of a specified service

Rate of Work: the volume of work per unit time

25 Service Level Agreement: an agreement between a WPC and the CA, which commits the WPC to undertaking a given work profile and the CA to supplying it. Price, rate, quality etc. parameters are specified for each work item category present in the SLA. Note that SLAs refer to an ongoing agreement, rather than a one-off

Steady state operation : the WMC is in equilibrium (the rate at which work leaves the WMC is equal to the rate at which work enters the WMC)

30 Volume of Work : amount of work

Process definition : "The representation of a business process in a form which supports automated manipulation, such as modelling, or enactment by a workflow management system...."

Workflow: "The automation of a business process, in whole or part, during which documents, information or tasks are passed from one participant to another for action, according to a set of procedural rules."

Workflow Management System: "A system that defines, creates and manages the execution of workflows through the use of software, running on one or more workflow engines, which is able to interpret the process definition, interact with workflow participants and, where required, invoke the use of Information Technology (IT) tools and applications"

Workflow Enactment Service: "A software service that may consist of one or more workflow engines in order to create, manage and execute workflow instances. Applications may interface to this service via the workflow application programming interface (part of WAPI)."

#### CORRESPONDENCE HANDLING CENTRE

Referring to Figure 1, the correspondence handling centre (CHC) 120 which provides the domain for the workflow management system described below is that of an enterprise receiving a stream of correspondence from its customers concerning its service offerings. These requests are fed into the enterprise's Correspondence Handling Centre (CHC), an entity which may incorporate not only in-house processing facilities but also (or instead) one or more processing facilities that are operated by third-parties (i.e. out-sourced).

Referring to Figure 1, the Correspondence Handling Centre 120 is composed of a number of disparate Work Processing Centres (WPCs) 100 and a Central Administration (CA) 105. The CA 105 provides an interface to a user community for the receipt of work requests 115 and for issuing reports 125.

The CA 105 deals with all stages of the CHC business process, bar the processing of the individual work items, which is performed by the WPCs 100. An individual WPC 100 may either be co-located with the CA 105, or sited at a remote location. In practice a WPC 100 may act for more than one CA 105 but in the scenario discussed here, a WPC 100 will be associated with only one CA 105, and hence a single CHC. Similarly a CHC may service more than one

enterprise or an enterprise may use more than one CHC but again, a one-to-one relationship is represented here.

A CHC may handle all or part of the correspondence received by the enterprise it serves. This correspondence can be of many types, ranging from 5 requests to quote for new business, through complaints about existing goods or services, to requests to modify or remove/cease goods or services already provided.

#### CHC Processes

10

Referring to Figure 2, the processes carried out by the CHC can be simply represented in terms of six specific categories of activity, each of which is described briefly here (note that, of the six, only 'Processing' is performed by the WPCs 100, the rest being the concern of the CA 105):

15

##### 1. Reception 230:

Correspondence arrives at the CA 105 either in batches in the post or asynchronously by telephone, electronic mail, facsimile and/or similar means. Work arrival patterns and content are determined by factors outside of the control 20 of the CHC.

##### 2. Classification 225:

Work is typically classified by type and difficulty. A given piece of work may contain items of more than one type, requiring it to be decomposed into a number 25 of separate work items for classification, distribution and processing. These work items are then recombined before being passed on to Inspection.

##### 3. Distribution 205:

Work items are distributed to the WPCs 100 for processing. This distribution 30 activity is based on a complex mix of parameters which are used to match work items with available, appropriately skilled resources at the WPCs 100.

**4. Processing 210:**

Work items are processed at the WPCs 100, and are either returned for checking (if completed), or returned unprocessed for redistribution. Each WPC 100 has variable resource levels - it may be able to call in part-time staff at short notice or 5 put the regular staff onto overtime as and when required. Each WPC 100 also has its own operational profile due to the attributes of the resources available to it, and its overall business objectives.

**5. Inspection 215:**

10 Completed items are checked and reworked if necessary. Typically, the inspection activity will have one of three possible outcomes:

- \* major fix required - return item to WPC 100 for re-work;
- \* minor fix required - typically, fix item locally and forward to Dispatch;
- \* no fix required - forward item to Dispatch.

15

**6. Dispatch 220:**

Completed items are dispatched to the customer and records may be kept for future billing, customer query and auditing purposes.

20 Workflow management systems are known which will deal with this type of domain but they also have inherent problems. In particular:

- \* the inability to cope with dynamic changes in resource levels and task availability;
- 25 \* a lack of resource management facilities;
- \* inadequate exception handling, especially during the processing of decomposed items;
- \* a limited ability to predict changes, due to external events, in both the type and volume of work entering the business process;
- 30 \* the inability to improve dynamically both the business process and how it is managed;
- \* a limited or non-existent ability to manage the decomposition and recombination of complex items.

These shortcomings manifest themselves as a mismatch between the actual capacity of a WPC 100 and the work offered to it at a given time. This in turn leads to sub-optimum throughput, necessitating wasteful over-provisioning of resources and/or backlogs of work. The present embodiment reduces some of these problems

#### SYSTEM ARCHITECTURE AND TECHNOLOGY

10 Referring to Figure 3, an embodiment of the present invention comprises an agent layer 300 which forms a layer above a Workflow Management System 305 which in turn controls the actual processing components 100 in the processing domain 310 of the correspondence handling centre. The CHC 120 consists of the WfMS 305 and a collection of tasks and resources, including the

15 WPCs 100, in its processing domain 310.

The agent layer 300 comprises at least one central administrative agent 320, and several work processing centre agents 325. Together the agents can determine resource allocation for dealing with workflow and in particular can deal with two different types of situations:

20 \* External exception - This occurs when there is a change in the overall workload presented to the CHC 120. The CA Agent 320 is informed and initiates a dialogue with the WPC Agents 325.

25 \* Internal exception - This situation arises when a resource exception occurs at a WPC 100 (for instance a 'flu' epidemic may render a large part of the workforce unfit for work). This exception is reported to the appropriate WPC Agent 325 by the WPC 100 in the processing domain 310, and the WPC Agent 325 instigates a negotiation with the CA Agent 320.

30 In both cases, the agents of the agent layer 300 attempt to form a distribution plan, to show how required changes to overall workload or current work distribution could be achieved.

The CAA's chief function is to co-ordinate the distribution of work across the processing centres (the WPCs 100) in the most efficient manner possible. This is achieved via negotiations between the CAA 320 and the various WPCAs 325 - the aim being to establish new contracts to cover the changed workload.

5 Note that there is no inter-WPCA communication at any stage, as the WPCAs 325 are only aware of the existence of the CAA 320, and not the other WPCAs that form part of a given AEW environment.

All the Workflow Agents 320, 325 are autonomous so they function independently when negotiating for new contracts, or for changes to existing 10 ones. Each WPCA 325 has knowledge of the work commitments of its own WPC 100, and negotiates to obtain a workload that will ensure its resources are utilised in the most efficient manner possible. Both the CAA and the WPCAs are attempting to meet their individual business objectives, and the details of the negotiations are geared towards achieving these ends.

15

#### AEW Technology Overview

Referring to Figure 5, the WfMS implements the CHC business process; the CHC domain drives work through the WfMS in accordance with the current 20 version of the distribution plan.

A three-tier architecture can be seen, with a Frontware layer of information and control GUIs, a Middleware layer comprising the distribution mechanism, and the Backware layer made up of the functional engines of the various components.

25 Backware: In order to allow platform independence, the Workflow Agents are implemented in Java using the JDK1.1 development kit. The WfMS is a commercially available third-party product.

Middleware: This is based upon a commercially available, CORBA 2-compliant, distributed computing platform, and comes in two different flavours:

30 Java to Java (for inter- and intra-agent, and agent to Frontware communication); Java to C++ (for agent to WfMS and agent to CHC domain simulator communication).

Frontware: The Workflow Agents use GUIs implemented in Java to provide administration and reporting tools to the end user. The WfMS uses proprietary administration tools, running on a PC platform. Multi-threading allows a single client to make concurrent calls to the WfMS, and the same call to be made by a number of clients concurrently. This means that all the Workflow Agents are able to monitor work as it passes through the WfMS and the CAA can update the contents of the SLAs as and when its negotiations with the various WPCAs are concluded.

Referring to Figure 11, the software architecture of Figure 5, is 10 implemented in this embodiment by four computers 1000; 1100; 1200; 1300. The CAA agent is provided on a first computer 1000. The location of this computer may, for example be close to that of the customer supplying work, or the headquarters of the call handling centre.

The computers 1100, 1200, 1300 are conveniently, as shown, the same 15 computers on which the work processes 305 are performed. Thus, the work process agents 100 are co-located with the work to be performed, and are arranged to receive messages therefrom, in the format defined by the workflow management system to which the work processes confirm (i.e. the above mentioned standard) indicating the changes in the ability of the work process to 20 do work. Conveniently, the computers 1100, 1200, 1300 comprise keyboards (not shown) via which human operators of the computers, performing the correspondence answering process, can input data indicating a change in their ability to work (for example their presence or absence).

## 25 Workflow Agent Architecture

Referring to Figure 4, both types of Workflow Agent currently implemented have the same basic architecture. However, their business objectives and the details of their constituent modules differ.

30 Both the CAA and WPCA communication modules 400 perform similar functions - they enable their respective agent to communicate with the outside world (i.e. with other Workflow Agents, the underlying WfMS and humans, via GUIs), and provide a channel for intra-agent communication.

The Workflow Agents' Environment Models 405 contain knowledge of their own operational characteristics; the Collaboration Modules 410 contain the algorithms and strategies that are used while negotiating for contracts; and the Co-ordination Modules 415 are responsible for all aspects of the Workflow

5 Agents' functionality other than communication and collaboration.

Service Level Agreements (SLAs) are stored in the environment model 405, together with residue queues. These are further discussed below.

**Service Level Agreements**

10

The purpose of an SLA is to record an agreement between the CA 105 and an individual WPC 100. The agreement is binding in both directions; in that the CA undertakes to provide a certain work profile at a given rate, and the WPC undertakes to process it. All of the agents make use of a common information

15 model and understand the same thing about work categories, rates etc.

Thus the notion of service is entity dependant: a WPC 100 receives a work-item provision service from the CA 105; the CA 105 receives work-processing services from its WPCs 100. These services are on-going, in that each has a duration (which may be infinite - which in effect means 'until further notice') and a start

20 time (which allows a service to be planned in for commencement at a later date/time).

An SLA includes the parameters detailed in Table 1. Given this format for an SLA, it follows that there will be a number of SLAs in place between each WPC 100 and the CA 105 (i.e. one for each work category).

25

Identity	The SLA's unique ID
CA Id	Unique identifier of the CA bound by this agreement
WPC Id	Unique identifier of the WPC bound by this agreement
Work category	An entry indicating the type of work for which this SLA is in place
Rate	The volume of work items per time unit (however defined) that the WPC Agent has agreed to process
Quality	Quality control parameter (e.g. % of jobs that will require no rework)

Price	The price (paid by the CA) for these work items to be processed
Recall	The price paid by the WPC Agent, if it is unable to process the work items specified in this SLA
Penalty	
Start Time	The time at which the service will be available
Duration	The length of time the service will be provided for

Table 1: The structure of an SLA

SLAs are updated accordingly to reflect any negotiated changes to the  
5 distribution of work amongst the WPCs 100.

#### CAA-Specific Architecture

The CAA's Environment Model 405 maintains records relating to all work  
10 submitted to the CHC for processing. These records cover three separate  
categories: allocated, unallocated and unavailable batches of work. The records  
for unallocated and unavailable batches can be in the form of "residue queues".

Allocated batches - the Environment Model 405 is aware of all work that  
has been allocated as a result of successful inter-agent negotiations, as it holds a  
15 local copy of all the SLAs that have been placed with the WPCAs 325.

Unallocated batches - It also records work, in the form of a list or queue,  
that has been submitted to the CHC but could not be distributed at the first  
attempt because insufficient processing capacity was available at that time. The  
WPCAs 325 are at liberty to under-bid (bid for less work than the bid request  
20 specified) during any phase of the negotiation, which may lead to a cumulative  
under-bid across the CHC as whole. The CAA 320 has no choice but to record  
any such under-bid, and attempts to distribute the resulting residual work by  
combining details of its type and rate with the contents of the next delta received.  
This is done with a view to forming an enlarged bid request for dissemination to  
25 the WPCAs 325 in the usual fashion.

Unavailable batches - Similarly, the CAA's Environment Model keeps track  
of internal requests for work that could not be satisfied at the time. These  
requests are communicated via over-bids (bidding for more work than the bid

request specified) from individual WPCAs to the CAA. The CAA attempts to satisfy these requests by checking the records relating to unallocated batches and adding any matching (in terms of rate, quality and processing period, by work type) items to the distribution plan, then updating the list of unallocated batches.

5. If the request cannot be satisfied in this fashion, the CAA notes the request, and attempts to satisfy it upon receipt of the next delta. If the delta contains items that match the request, these are added to the next distribution plan, and omitted from the subsequent bid request sent out by the CAA.

The unallocated and unavailable batches mentioned above can be stored

- 10 by the CAA as "residue queues" which can be "excess" or "deficit" queues.

The other key function of this Environment Model is to provide both directory information and name server functionality so that the CAA can locate and communicate with the WPCAs that act for the WPCs belonging to the CHC.

- 15 The Co-ordination Module determines the algorithm used to re-formulate the distribution plan, in an attempt to accommodate successive changes in the amount of work that can be processed by the CHC as a whole. It has recourse to the details of any unallocated or unavailable batches, and implements the attempts to match these to portions of the most recently received delta.

- 20 The Collaboration Module executes the collaboration strategy used by the CAA to obtain offers from the WPCAs for changing the contract governing the workload of their WPCs.

#### WPCA-Specific Architecture

- 25 The WPCA Environment Model 405 is responsible for maintaining records of work it has agreed to accept from the CAA 320. It does this by holding local copies of any current contracts (SLAs) it has successfully negotiated for. It is also responsible for maintaining its resource model and price profile.

- 30 Its Co-ordination module 415 gathers together all information relating to the WPC's ability to process work - this must be up to date in order to allow the WPCA 325 to make realistic, timely responses on receipt of bid requests from the CAA 320.

The Collaboration Module executes the collaboration strategy used by the WPCA 325 to generate responses to the CAA's requests to change the contracts governing the workload of its WPC 100.

## 5 Deltas

The Workflow Management System will normally be in a steady state. Any steady state is likely to be temporary however, as the requirement for work may increase or decrease over time, and resource levels at the WPCs 100 can 10 change. Such a perturbation is referred to as a delta (or ' $\Delta$ ').

The delta is a vector quantity, and includes the parameters shown in Table 2.

$\Delta$ identity					
Work category	Source	Rate	Quality	Start Time	Duration
Work_Cat_1	External	$\Delta v_1$	$\Delta q_1$	$st_1$	$d_1$
Work_Cat_2	External	$\Delta v_2$	$\Delta q_2$	$st_2$	$d_2$
.	.	.	.	.	.
Work_Cat_N	External	$\Delta v_N$	$\Delta q_N$	$st_N$	$d_N$

15 Table 2: Details of a Delta

An entry of the form  $\Delta v_i$  indicates an increase/decrease in the rate of work category  $i$ . Similarly  $\Delta q_i$  indicates a change in the quality of work  $i$ . Note that  $\Delta v_i$  or  $(\Delta q_i)$  may be zero (i.e. no change to rate/quality of that type of work 20 item). There will be an entry for each category of work handled by the system, even if no change is required. The source of a delta can be either 'External' (to indicate that it originated from outside of the WMC) or the identifier of a particular WPC (to identify the WPC that is requesting a change to its current workload). An example external  $\Delta$  is shown in Table 3, and an example internal  $\Delta$  is shown in 25 Table 4.

Deltas can be 'positive' and 'negative'. A positive delta is one in which all the non-zero rate values are positive (e.g. Table 3), whereas a negative delta is

one in which all the non-zero rate values are negative (e.g. Table 4). A mixed delta is one which contains a mixture of both positive and negative non-zero rate values. It follows that deltas may be broadly characterised as being either external or internal, and either positive or negative or mixed.

5

$\Delta\text{identity} = \Delta 1$ Work category	Source	Rate	Quality	Start Time	Duration
A	External	+ 30	0	NOW	INFINITE
B	External	0	0	NOW	INFINITE
C	External	+ 20	+ 10%	NOW	INFINITE

Table 3: An example external delta

$\Delta\text{identity} = \Delta 2$ Work category	Source	Rate	Quality	Start Time	Duration
A	WPC2	-10	0	NOW	INFINITE
B	WPC2	0	0	NOW	INFINITE
C	WPC2	-5	0	NOW	INFINITE

10 Table 4: An example internal delta

#### OVERVIEW OF WORKFLOW AGENT COLLABORATION

Referring to Figure 6, the co-ordination strategy used by the Workflow Agents in this scenario uses a combination of Contract Net and limited Contract Net protocols. These are published in: 'Negotiation as a metaphor for distributed problem solving' by Davis R and Smith RG, in Artificial Intelligence, No 20, pp63-109 (1983), and: 'The Contract Protocol: High-Level Communication and Control in a Distributed Problem Solver', by Smith RG, IEEE Trans. on Computing, 29, No 12 (December 1980). The difference between the two is that Contract Net always announces the start of the bidding process to all available contractors, whereas limited Contract Net announces to a specific sub-set of contractors. The Workflow Agents 320, 325 combine both by opening the negotiation process by

inviting all associated WPCAs to bid, then progressively excluding successful bidders, as shown in Figure 6.

In Contract Net terms, the CAA 320 assumes the role of the human manager by dividing the problem (work distribution) into sub-problems 5 (distributing work items), searches for contractors to carry out tasks and monitors the overall solution by maintaining local copies of all its contracts. The WPCAs 325 assume the role of human representatives of the contractors who carry out sub-tasks (processing work items). This is not a 'zero-sum game', that is the WPCA 325 can increase the profits of its WPC 100 at the same time as helping 10 the CAA 320 to increase the profits of the CA 105. Agents in the role of managers locate suitable contractors via an activity of bidding which proceeds as follows (taken from: 'Co-ordination in Multi-Agent Systems', by Nwana HS, Lee L and Jennings NR, in Nwana H S and Azarmi N (Ed): 'Software Agents and Soft Computing - Towards Enhancing Machine Intelligence', Springer, pp42-58 15 (1997)):

- \* a manager announces a task;
- \* contractors evaluate the task with respect to their own abilities and commitments;
- 20 \* contractors table bids to the manager;
- \* the manager evaluates received bids, chooses a contractor and awards the contract to it;
- \* the manager waits for the result of the contract.

25 The following section contains simple, worked examples for both an external and an internal delta. Only work rate and price attributes are shown, and not all of the possible search space is explored. It is assumed that no over-bids are received in either case.

There are three WPCAs 325 used in these examples (WPC1A, WPC2A 30 and WPC3A) and three work item types designated A, B and C.

**Handling an External Delta (Including Example)**

Upon receipt of an external delta, the CAA 320 multi-casts (i.e. sends a message addressed to all appropriate recipients) a bid request to the WPCAs 325.

- 5 This bid request contains various details for each category of work that the CAA 320 is trying to distribute, including required start and end times, work rate (i.e. items per unit time) and quality threshold. Each WPC Agent 325 then uses its Coordination module to determine its response in terms of quantity, quality, price etc. for each offered work category. The WPCA's Collaboration Module 410
- 10 sends this bid response to the CAA 320, though it can decline to respond if it cannot process any additional work in the time period specified in the original bid request.

As well as bidding for some or all of the offered work, the WPCA 325 may think it prudent to overbid, i.e. bid for more work than was actually offered by the CAA 320. Overbidding might occur when a WPCA cannot fulfil a bid request unless it brings additional resources on-line. In order to fully utilise these extra resources, it may require more work than is currently on offer, hence it overbids. If accepted, the CAA records the details of the overbid, with a view to offsetting it against the contents of subsequent deltas.

- 15
- 20 The CAA 320 either waits for replies from all of the WPCAs 325 to arrive or for some pre-determined time-out period to expire. Then the cost factor (which takes into account the bid price, difference in bid and response quantity, quality etc. for each work category included in the initial bid request) is calculated for each bid received, and the bids are ranked by ascending cost.

- 25 The lowest 'cost' bid is used as the basis for the next round of negotiation (see below for a discussion of 'cost' and 'cost factors'). If this bid accounts for all the offered work, then this branch of the negotiation is terminated. Otherwise the CAA 320 narrowcasts a new bid request message to cover the difference between the quantity (per unit time) of each work type 30 covered by the bid response with the lowest cost factor, and the requested rate for each work category contained in the original, multicast, bid request. This difference represents the work that would not be distributed if the CAA 320 simply accepted a single, lowest cost bid. The WPCA 325 that supplied the

lowest cost bid is excluded from the list of recipients. The CAA 320 receives another set of bid responses, ranks them in ascending cost as before, and calculates the difference between requested and offered work rates, also as before. This process continues until either all of the work has been accounted for, 5 or there are no more WPCAs 325 to solicit bids from. Any outstanding work is recorded for distribution at a later time.

The CAA 320 has now established a baseline cost for placing some or all of the work contained in the external delta. It now repeats the 'multicast, followed by exhaustive narrowcast' process for each of the remaining, initial bid 10 responses. However, it can now prune the search space by comparing the cumulative cost, after each round of bidding, with the baseline cost - the current branch of the search is abandoned if the baseline cost is exceeded.

Once the lowest cost, available (as opposed to ideal) solution has been found, the CAA 320 records the details of the new contracts that it has 15 negotiated and forwards the updated distribution plan to the WfMS 305 for implementation.

Suppose the following (simplified) external delta arrives at the CA Agent:

(20A, 10B, 5C)

This indicates that an additional 20 work items of type A per unit time, 20 10 of type B and 5 of type C are arriving at Reception.

#### Contract Net Phase

A multicast bid request covering this additional work is sent out to all 25 WPC Agents:

"Can you process (20A, 10B, 5C) extra work items per unit time?"

The WPC Agents return the following offers:

"(x1A, y1B, z1C) @ price U" from WPC1A;  
30 "(x2A, y2B, z2C) @ price V" from WPC2A;  
"(x3A, y3B, z3C) @ price W" from WPC3A.

This indicates to the CAA 320 that:

WPC1A can accommodate an additional  $x_1$  work items of type A per unit time,  $y_1$  work items of type B and  $z_1$  work items of type C at a total price of  $U$ ,

WPC2A can accommodate an additional  $x_2$  work items of type A per unit time,  $y_2$  work items of type B and  $z_2$  work items of type C at a total price of  $V$ , and

WPC3A can accommodate an additional  $x_3$  work items of type A per unit time,  $y_3$  work items of type B and  $z_3$  work items of type C at a total price of  $W$ .

The cost factor is calculated using a comparative function, the general form of which is:

$$CF = w_1 f_1(x) + w_2 f_2(x) \dots + w_n f_n(x)$$

where each  $f_n(x)$  represents the evaluation of a quantitative aspect of the bid response (i.e. rate, quality, timeliness), and each  $w_n$  represents the relative importance of a term. In practice it was useful to enforce the following constraint:  $w_1 + w_2 + \dots + w_n = 1$

The weights are used to reflect the current business priorities of the CAA  
320. In this example we enforce a 'maximum work distribution is much more important than price, all other factors are ignored' policy, by setting the rate weight  $w_1 = 0.8$ , the price weight  $w_2 = 0.2$  and all the other weights to zero.

20 The cost factor for each bid response is now calculated by the CAA:

$$CF_1 = 0.8( (20-x_1) + (10-y_1) + (5-z_1) ) + 0.2U \quad \text{for WPC1A's initial bid}$$

$$CF_2 = 0.8( (20-x_2) + (10-y_2) + (5-z_2) ) + 0.2V \quad \text{for WPC2A's initial bid}$$

$$CF_3 = 0.8( (20-x_3) + (10-y_3) + (5-z_3) ) + 0.2W \quad \text{for WPC3A's initial bid}$$

25 If WPC1A's bid has the lowest cost factor, and WPC3A's the highest, and none of the responses exactly matched the work rates contained in the initial bid request, then the negotiation proceeds, starting from the lowest cost (i.e. WPC1A's) bid response.

### 30 Limited Contract Net Phase

A narrowcast bid request is sent out to WPC2A and WPC3A:

"Can you process ( (20 - x1)A + (10 - y1)B + (5-z1)C ) extra work items per unit time?"

The bid responses are as follows:

"(x21A, y21B, z21C) @ price X" from WPC2A;

5 " (x31A, y31B, z31C) @ price Y" from WPC3A.

The cost factors are calculated as before:

CF21 = 0.8( (20-x1-x21) + (10-y1-y21) + (5-z1-z21) ) + 0.2X for WPC2A's second bid

CF31 = 0.8( (20-x1-x31) + (10-y1-y31) + (5-z1-z31) ) + 0.2Y for WPC3A's

10 second bid

Provided that neither bid response exactly matched the work rates contained in the second bid request, and assuming that CF21 < CF31 (i.e. WPC2A's bid was the 'best' of the two), a final narrowcast message is sent (in this case to WPC3A only):

15 "Can you process ( (20-x-x21)A + (10-y-y21)B + (5-z-z21)C ) work items per unit time?"

The final bid response of this round of the negotiation is received:

"(x321A, y321B, z321C) @ price Z" from WPC3A.

The baseline cost is calculated by summing the cost of the individual

20 successful bids:

Costbaseline = 0.8( (20-x-x21-x321) + (10-y-y21-y321) + (5-z-z21-z321) ) + 0.2(U + X + Z)

(Note that the intermediate branches are also explored in ascending cost factor

25 order, but that this has been omitted from the example for the sake of brevity).

#### Subsequent Iterations

The Limited Contract Net phase is repeated twice, commencing each time 30 with the next 'best' bid received from the initial Contract Net phase. The difference being that after each step, the cumulative cost is compared with the baseline cost, and the negotiation is abandoned if the baseline cost has been

exceeded. Once the CAA has determined the lowest cost solution, it places contracts with the successful bidders and records the work rate residue (if any).

#### Handling an Internal Delta

5

When a WPCA 325 is alerted that its WPC's 100 ability to process work has been reduced for any reason (e.g. 'flu' epidemic, local public holiday) it generates an internal delta. This contains details of the types and rates of work that the underlying WPC 100 wishes to shed (in WfMS terms, return unprocessed to the CA 105); along with the details of the period for which shedding is requested, and is sent to the CAA 320. Upon receipt, it is converted to the equivalent of an external delta, by the simple expedient of reversing the signs of the work rate values. The negotiation protocol is then very similar to that for an external delta, the one difference being that the initial bid request message is not sent to all WPC Agents as before, rather a narrowcast is sent to all WPC Agents bar the one that raised the internal delta.

Suppose WPC2A generates a request to reduce its type B workload by 5 items per unit time. It sends the following internal delta to the CAA (all other details omitted):

20 (0A, -5B, 0C)

#### Limited Contract Net Phase

The CA Agent reverses the polarity of any non-zero rates, checks its records for work owed due to previous over-bidding and, if the delta cannot be offset from this, sends a narrowcast message to the other two WPCAs:

"Can you process (0A, 5B, 0C) extra work items per unit time?"

The bid responses are as follows:

30 (0, y1B, 0) @ price X from WPC1A;  
(0, y3B, 0) @ price Y from WPC3A.

The cost factors are calculated as before:

$$CF1 = 0.8( (5-y1) ) + 0.2X \quad \text{for WPC1A's initial bid}$$

$$CF3 = 0.8( (5-y3) ) + 0.2Y \quad \text{for WPC3A's initial bid}$$

Provided that neither bid response exactly matched the work rates contained in the initial bid request, and assuming that  $CF1 < CF3$  (i.e. WPC1A's bid was the 'best' of the two), a final narrowcast message is sent (in this case to WPC3A only):

"Can you process ( (5-y1)B ) work items per unit time?"

The final bid response of this round of the negotiation is received:

10 " (y31B) @ price Z" from WPC3A.

The baseline cost is calculated by summing the cost of the individual successful bids:

$$\text{Costbaseline} = 0.8( (5-y1-y31) ) + 0.2(X + Z)$$

## 15 Subsequent Iterations

The Limited Contract Net phase is repeated, but using WPC3A's initial bid this time. Again, the cumulative cost is compared with the baseline cost, and the negotiation is abandoned if the baseline cost is exceeded.

20 Once the CAA 320 has determined the lowest cost solution, it places contracts with the successful bidders and records the work rate residue (if any). It then updates WPC2A's contract to record the fact that the type B work rate has been reduced by 5 items, for the period specified (but not shown here) in the internal delta.

25 A description of the algorithm will now be given in greater detail with reference to Figures 12a to 12d.

In step 2002, as described above, the CA agent broadcasts the original amount of work to all WPCAs.

30 In step 2004, the process of Figure 12b is called. Referring to Figure 12b, in step 2006, replies are received from the WPCAs. In step 2008, the routine of Figure 12c is called.

Referring to Figure 12c, in step 2010, for each of the replies, a running price total is calculated comprising the sum of the price specified in the reply, and

that previously calculated in the last stage of the algorithm (which is zero for the first round).

In step 2012, the running price is compared with the stored baseline price (if any), and if the price is greater than the baseline price then that branch is 5 rejected and not further considered (step 2014).

Next, in 2016, it is determined whether each of the returned quantities matches exactly the transmitted quantity (step 2016) and, if so, the price (which, it will be recalled, is lower than the existing baseline price) is made the new baseline price and the details of the corresponding contracts with the WPCAs 10 making up the running price are stored as the baseline allocation (step 2018).

If the quantity concerned did not exactly match (i.e. was less than) the quantity transmitted, then as described above the cost factor for the bid is calculated (step 2020).

If the last received signal has been processed (step 2022), the process of 15 Figure 12c returns; otherwise (step 2024) the next received bid signal is processed.

Thus, the process of Figure 12c exits with the lowest received exact allocation stored as the baseline allocation and its total price stored as the baseline price; and with all partial solutions having associated cost factors 20 calculated.

Returning now to Figure 12b, in step 2030, any such partial bids are ranked by cost factor. On having reached the last partial bid (i.e. if there are none left to consider) the process of Figure 12b exits. Figure 12b will therefore exit at the end of a given round of signalling (step 2032).

25 If not, then the lowest cost remaining partial allocation to be considered is selected (step 2034) and the routine of Figure 12c is selected.

Referring to Figure 12c, in step 2040, the remaining source quantity which would be required if the previous partial bid were used as a basis is calculated, by adding to a running total of the quantities previously bid in 30 preceding rounds the amount bid in the bid being considered and subtracting this from the total amount original required (step 2040).

In step 2042, this remaining amount is transmitted to all WPCAs other than that which gave rise to the bid now being considered. (For the avoidance of

doubt, it will be understood that these include WPCAs which have previously made bids on previous rounds. All such previous bids from WPCAs are, at this stage, neither accepted or rejected but "on hold" while the CAA evaluates the best allocation).

5. Next, in step 2044, the routine of Figure 12b is called once more, to evaluate this next round of bids. It will be understood that, by using recursion, each of the routines of 12b, 12c, and 12d can be called from within itself, partial results being stored on stacks until the return from each level of recursion.

On completing execution of the process of Figure 12b, the process of  
10 Figure 12c returns.

On the final return from the process of Figure 12b, referring to Figure 12a, in step 2050 the CAA determines whether (as should be the case) a baseline allocation (comprising one or several (price, quantity) offers from WPCAs) is stored. If so, in step 2052, the CAA signals, to each WPCA, acceptance of that  
15 (price quantity) offer (step 2054) and the details are recorded as described above.

If the amounts of the allocation do not match the original requirement, or if no baseline was derived, then the residue is stacked on a residue queue (step 2056) and added into the next received external delta.

Thus, the effect of the algorithm is to perform a depth-first search for  
20 solutions, taking each of the replies at each stage of negotiations for each branch, in turn.

Whereas this would potentially result in a very large number of communications between the agents, requiring substantial bandwidth and/or long delay in determining a resource allocation, by the use of a baseline price (which is  
25 preferably updated as successively better solutions are found) more and more possible branches are excluded as the search proceeds.

It will be understood that substantially the same algorithm is performed when an internal delta is received, except that the work processing centre agent which gave rise to the internal delta is not contacted during at least the first  
30 round (and possibly further rounds) of the negotiation process.

The above described process is preferably improved, as discussed above, by further modifications to reduce the number of solutions evaluated (for example, the signalling of a maximum price by the CA agent as discussed above).

### WMC AGENT OPERATION

The WMC Agent's aim is to enhance the distribution process by establishing formal agreements between the WPCs and the CA (i.e. the SLAs) that are intended to regulate the flow of work items through the Workflow System. These negotiated agreements underpin each distribution plan that the CA Agent proposes to the User. Any proposed changes to an existing SLA requires the consent of both the CA 105 and the WPC 100 in the first instance, and eventual approval by the User.

The CA Agent 320 could form a centralised distribution plan in isolation (and consequently the WPC Agents 325 would have a dubious claim to agenthood, due to their lack of autonomy), if it had detailed knowledge of the resources, workload, price profile etc. of each WPC 100. However it is more realistic to assume that this knowledge is preferred not be widely available. Therefore direct access to it is restricted to the agent(s) responsible for a given WPC 100.

In order for the negotiation to proceed, the WPC Agents are asked questions such as the following:

- 20 1. "Can you increase your rate of type A work by 30 items per unit time from <start time> for <duration>?"
2. "Can you increase your rate of type A work by 30 items per unit time from <start time> for <duration> for a price less than or equal to 50?"

For a WPC Agent to be able to answer these questions, it must have access to knowledge about the capabilities of its WPC, such as the rate and profile of work that the WPC is committed to. It is assumed that it will have access to the details of the available workforce, such as the number of workers, their skills, rates of pay, and other factors that influence the price profile.

All of these factors will be brought to bear in a complex calculation which will result in an answer of one of the following forms:

- 30 1. "I can increase my rate of type A work by 30 items from <start time> for <duration> at a total price of 34"

2. "I can increase my rate of type A work by 25 items from <start time> for <duration>, and the price for this will be 20"

3. "I can increase my rate of type A work by 40 items from <start time> for <duration> at a total price of 25"

5. Each response can be categorised as either an underbid, an matching bid or an overbid. Note however that 'under', 'match' and 'over' refer to individual attributes of the initial query (e.g. rate or quality) but not all (i.e. rate, quality, start time, duration or price).

10. \* Underbid - It will be noted from the responses that the WPC may not be able to process the required number of work items exactly. Instead it may be able to process less, as in case 2.

\* Matching bid - In addition the WPC may be able to increase its resources (by hiring extra workers for instance), in order to process the extra work items.

15. \* Overbid - However it may be the case that the WPC is unable to bring in just enough workers to process the extra work items, resulting in an overbid. The underlying reason for this is assumed to be a non-linear constraint between the number of extra workers brought in and the volume of work that they can perform, per unit time.

When an overbid occurs, the CA Agent has two main options, it can  
20. either canvass other WPC Agents to see if they would be willing to relinquish work (albeit at a price) which could then be reallocated to the overbidding agent, or the overbid can be accepted and paid for by the CA Agent, which will then have some 'credit' with a particular WPC Agent, which should be taken up as soon as possible.

25. There are two other types of response that a WPC Agent can make:

\* Accept - this is an extreme form of the matching bid, as the WPC Agent undertakes to match all the requested attributes (i.e. rate and quality, and start time and duration and price);  
30. \* Reject - this is an extreme form of the underbid, as the WPC Agent indicates that it is currently unwilling/unable to undertake any change to its existing work rate.

When the CA Agent receives a bid that it finds potentially acceptable, it must put the bidding WPC Agent on hold, whilst it explores the implications of

accepting that bid. It is not computationally feasible to consider every bid received as being potentially acceptable, as the time taken to explore all of the possibilities would be a non-polynomial function of the number of WPC Agents present. (See discussion below of search options for the WMC Agents.)

5

### Price Profiles

Referring to Figure 7, in order to perform this calculation, the agents need data relating to the "real" work processing world. The type of data needed can be

10 abstracted from a detailed knowledge of the resources available at the WPC 100 and the capabilities of these resources, and stored as a price profile at each of the WPC Agents. There will be one price profile 700 per work category. An example is shown in Figure 7 and the use of price profiles is illustrated in the section "Scenario Types" below.

15 The x-axis of the price profile represents a delta (a change in the rate of work). A positive value indicates the increase in the rate at which the WPC 100 is being asked to process work. A negative value represents work items (the volume per unit time) that the CA 105 might want to buy back from the WPC. The y-axis has two meanings. When the delta is positive, it represents the minimum 20 acceptable price (paid by the CA) in order for the WPC to process the extra work items. When the delta is negative, the y-axis represents the penalty price4 (paid by the CA) in order to buy back some work items from the WPC. (A penalty price might arise if a WPC 100 agrees to a CA's request to relinquish work.)

It should be noted that the profiles are non-linear. This has an important 25 consequence for the negotiation between the agents. If the profiles were linear and WPC Agents provided responses of the form 2 above, then over a period of time the CA Agent could reason that the relationship was linear and even infer the exact form of the linearity. If this were the case it would no longer need to ask each WPC Agent whether or not it could perform the work items and at what 30 price, since it could determine this itself. However, a more realistic situation is that the profiles are dynamic over time. Thus the exact form of the non-linearity is not fixed.

It should also be noted that there could of course be more than three WPC agents. Although there are types of interactions between three agents that have no counterpart in two agents, all of the interactions involving four or more agents have a counterpart (albeit simpler) in three agents. Thus the example 5 described above, using three agents, is sufficient to underpin much richer interactions. (However, it should be noted that the algorithm described below in the section entitled "Scenario Types" will scale non-linearly (i.e. quadratically) with the number of WPC Agents..

## 10 Pricing Considerations

The detailed pricing to be performed by the WPC agents, briefly discussed above, do not form part of the present invention; the mechanism by which a resource is priced is specific to the particular resource concerned.

15 Nonetheless, in general, the process of deriving a price consists in monitoring the availability of resources (e.g. number of staff available); monitoring the current volume of work; calculating the available fraction of resources (the unallocated resources); storing some data representative of the cost of the resources available (staff costs and overheads); and calculating a price for doing 20 new work which takes into account the costs of resources, and in the incremental cost of taking on the new work.

For example, if a given work handling centre consists of four persons, all 25 fully occupied, then the cost of taking on additional work includes the cost of an extra person, which introduces a fixed cost regardless of whether the additional work occupies 1% or 100% of the capacity of that person, as well as variable costs related to the volume of work. Thus, a cost for performing exactly the volume of work specified can be quoted.

By way of contrast, where one person is 50% occupied by existing work, the price of taking on additional work will rise at a (relatively low) first rate until 30 that person is fully occupied, at which point the rate of rise of price with volume of work will change (due to the need for an additional person).

Accordingly, the pricing mechanism is preferably arranged to be capable of locating such discontinuities in the price/volume curve shown in Figure 7 for

amounts lower than the required quantity specified by the CAA agent, and to be capable of bidding for an amount which efficiently utilises the available resources; in this case, by accepting work equivalent to the 50% of one person workload, or, in general, a volume of work falling within a discontinuity in the price/volume

5 curve.

In this way, WPCAs are capable of bidding economical prices for lower volumes of work than those specified.

One example of an algorithm will now be described.

Briefly, referring to Figure 13, in a step 3002, the WPC agent receives a  
10 bid quantity signal from the CAA agent. In a step 3004, it calculates a price for supplying the required quantity.

In a step 3006, a plurality of prices for progressively lower quantities (lower than the initial quantity signalled) are also calculated, and in a step 3008, it is determined whether any of these would be more profitable (i.e. enable the  
15 provision of services at a lower price). If so, then in a step 3010, the lowest such price and quantity are substituted for the original price and quantity.

In a step 3012, the price and quantity thus derived are signalled back to the CAA agent.

Then, in a step 3014, the WPC agent awaits a further signal from the  
20 CAA agent.

If the signal received is a rejection, then the negotiation process is terminated, and all temporarily stored price and quantity data is erased.

Alternatively, a further bid quantity signal may be received, specifying a different quantity. In this case, the previously transmitted quantity and price data  
25 is temporarily stored, since the CAA agent may later return to accept (as discussed below) that proposal. Then, ignoring the temporarily stored data, the process returns to step 3002 to calculate a fresh price for the revised quantity signalled (on the assumption that the WPC agent will not receive an acceptance of the previous offer).

30 Finally, the signal received at step 3004 may be an acceptance signal from the CA agent, specifying one of the price/quantity combinations previously indicated by the WPC agent. In this case, the temporarily stored details of that

offer are retrieved by the WPC agent, which proceeds to set up a contract in step 3006, in accordance with Contract Net Protocols, or as discussed above.

It will be understood that where, as discussed above, each work flow process can handle multiple different types of work, the calculation of an optimal 5 quantity and price is performed by varying several of the types of work to attempt to find different local minima of price against volumes.

#### Residue Queues

10 The CA Agent maintains two residue queues which are used to record details of short-term excesses and deficits in the number of work items respectively.

#### Excess Queue

15 The agents attempt to negotiate a work distribution plan. There are situations when the required number of work items cannot be distributed exactly, leading to a surplus. These surplus items are maintained on an excess queue, on a per work item category basis. Each entry is of the form:

20 *Work Item Category, Excess Rate*

When a new delta arrives, the CA Agent will modify it by combining any excess items with the delta.

25 *Deficit Queue*

In the process of distributing the work items whilst attempting to minimise cost, the CA Agent may make an undertaking to an agent to give it 30 some extra rate of work items when it can. This undertaking, or deficit, is recorded on a deficit queue, on a per work item category basis. The entry is of the form:

*Work Item Category, Deficit Rate, Owed to*

When a new delta arrives the CA Agent will first look to see if the deficits can be reduced or removed altogether by taking work items from the delta, and pre-assigning them to the WPCs that are in deficit.

An example is as follows. Initial excess and deficit queues are as shown in Table 5 and Table 6, and an incoming delta is shown in Table 7. Note that in each case 'rate' refers to a given volume of work per unit time.

Work Category	Excess rate
A	5
B	0
C	0

10.

Table 5: Example excess queue

Work Category	Deficit rate	Owed To
A	0	
B	-10	WPC1
C	-6	WPC3

Table 6: Example deficit queue

15

$\Delta$ identity = $\Delta 1$ Work Category	Source	Rate	Quality	Start Time	Duration
A	External	0	0	NOW	INFINITE
B	External	+50	0	NOW	INFINITE
C	External	+30	0	NOW	INFINITE

Table 7: Example external delta

Assuming that an external delta arrives (details as per Table 7), then the CA Agent will first remove the deficit owed to WPC1 to get a modified deficit queue

20

(as per Table 8) and revised delta (as per Table 9). The CA Agent also removes the deficit owed to WPC3 to give a modified deficit queue and revised delta as per Table 10 and Table 11 respectively.

Work Category	Rate	Owed To
A	0	-
B	0	-
C	-6	WPC3

5

Table 8: Modified deficit queue

$\Delta\text{identity} = \Delta 1$ Work category	Source	Rate	Quality	Start Time	Duration
A	External	0	0	NOW	INFINITE
B	External	+40	0	NOW	INFINITE
C	External	+30	0	NOW	INFINITE

Table 9: External delta, after first revision

10

Work Category	Rate	Owed To
A	0	-
B	0	-
C	0	-

Table 10: Final version of modified deficit queue

$\Delta\text{identity} = \Delta 1$	Source	Rate	Quality	Start Time	Duration
A	External	0	0	NOW	INFINITE
B	External	+40	0	NOW	INFINITE
C	External	+24	0	NOW	INFINITE

15 Table 11: External delta, after second revision

Finally, any excess queue items are added to the delta, resulting in a modified delta as per Table 12 and modified excess queue as per Table 13.

$\Delta$ identity = $\Delta$ 1	Source	Rate	Quality	Start Time	Duration
A	External	+5	0	NOW	INFINITE
B	External	+40	0	NOW	INFINITE
C	External	+24	0	NOW	INFINITE

5 Table 12: Final version of modified external delta

Work Category	Excess Rate
A	0
B	0
C	0

Table 13: Final version of modified excess queue

10 This residue queue management activity results in the formation of a partially complete work distribution plan, as shown in Table 14.

Work Item Category	WPC1	WPC2	WPC3
A	-	-	-
B	10	-	-
C	-	-	6

Table 14: Partial work distribution plan

15

#### Scenario types

Two types of scenario can be demonstrated. The first illustrates what happens when the workload offered to the WMC changes (in terms of either rate 20 or composition) and shows how the agents negotiate with each other in order to formulate a plan for redistributing the resultant work items i.e. an external delta.

The second type shows how the CA Agent reacts when WPC Agents request modifications to existing WPC workloads i.e. an internal delta. Examples of each type of scenario are described below.

### 5. Steady-state operation

Figure 8 illustrates the initial steady-state conditions. There are a number of SLAs in place between each of the WPCs 100 and the CA 105, which are causing WPCs 1, 2 & 3 to be operating at close to normal capacity, well below normal capacity and at normal capacity, respectively. Each WPC has a different price profile (as indicated by the graph adjacent to each) which determines its bidding policy for work items offered to it by the CA. Note that both of the CA Agent's residue queues are initially empty.

The introduction of an external delta represents a change in the workload offered to the WMC, whereas an internal delta represents a request to modify a WPC's existing workload. (The structure of a delta is discussed above.)

The mechanism for receiving a new external delta into the system is similar to that carried out for an internal delta, the difference being that the 'Source' will be set to the unique identifier of the WPC that raised the exception.

Load re-balancing is performed ultimately by the CA, and results in the updating of appropriate SLAs. However, the re-distribution plan that guides the CA is generated as a result of inter-agent negotiation. Negotiation can be initiated by either the CA Agent (for external deltas) or a WPC Agent (internal deltas).

Referring to Figure 9, the first scenario involves an influx of additional work to the WMC, which is seen as an external delta at the CA. In Figure 9 the delta has been shown as a simple, positive change in work rate. Deltas can of course be more complex, involving changes in quality requirements etc.

When an external delta is received by the CA 105, the details are passed to the CA Agent with a request for it to instigate a negotiation. The CA Agent's first step is to look in its deficit queue to see if some or all of the additional work can be accommodated using any spare capacity that has previously been negotiated and paid for but was not utilised for some reason. It will also look in its excess queue to see if any outstanding work is to be added to the incoming delta.

As the demonstration scenario starts from the steady-state this will not be the case first time round so the next step is to see which of the WPCs is willing and able to absorb the extra work.

To initiate this procedure a request message is broadcast to all the WPC

5 Agents asking if any of them is able to handle all or part of the additional work:

This message will contain the following information:

- \* A message ID - a unique identifier for the message;
- \* A sub-goal ID - a unique identifier relevant to the resolution of one item in a

10 delta;

- \* A context ID - a unique identifier relevant to each negotiation;
- \* The details of the delta - as shown in Table 2.

On receipt of the request, each WPC Agent will check to see if its WPC  
15 can handle all or part of the additional workload without further negotiation.

Depending on available resources, a WPC Agent will be able to bid as follows:

- \* Matching bid - All of the work regardless of type;
- \* Overbid - More work than was actually offered;

20 \* Underbid - Less than all of the work which will be a combination of one or more of the following:

- \* all of some types;
- \* some of all types;
- \* some of some types.

25 \* Accept bid - All of the work as per the requested quality and price parameters;

- \* Reject bid - None of the work.

If it can handle any additional work, the WPC Agent then consults its price profile to calculate a price for doing the work. This price is then returned to  
30 the CA Agent in a bid message which will consist of:

- \* A message ID;
- \* The same context ID;

- \* The same sub-goal ID, if required;
- \* The price for doing all or part of each type of work as appropriate.

5 The offers are made on the assumption that they are only valid for the lifetime of the negotiation.

The CA Agent will then wait for a response (or time-out, after a suitable period) from all interrogated WPC Agents and will then have to decide which offer to accept, if any. Assuming that the CA Agent is to attempt to get the work done at the minimum price to itself, it will check if the price supplied will cover all the 10 additional workload. If not, the CA Agent will have to consider the cost of assigning the unallocated work if it accepts the lowest cost partial offer. To do this, a message is sent to all WPC Agents (except the one that returned the lowest offer first time around) requesting prices for accepting the residual workload. This message will be similar to the first, except that it also includes a 15 maximum price which the CA Agent will have calculated by considering the difference between the lowest offer (regardless of work accepted) and the offer for doing all of the work, if applicable.

The next message will be of the form:

20 \* A message ID;  
\* The same sub-goal ID, if required;  
\* The same context ID;  
\* The amount of work of each type that is required;  
\* The maximum total price for doing the work.

25

Again, the WPC Agents may respond with a price for doing all or some of the work as detailed above. If there is no offer for doing all the work then the offer that would cover the most workload should be considered, and this process loop is repeated until the delta is satisfied or the closest approximation is reached.

30

The aim of the CA Agent may be to get the work done leaving the lowest possible deficit residue, in this case the strategy for selecting offers would be slightly different in that the percentage of work distributed would be the most important criteria to consider rather than lowest price.

Consideration should be given here to the situations where there is no close match or no match that would cover all of the work.

Assuming the minimum-cost scenario, a run-through of the stages of negotiation and calculation is shown below:

5 As shown in Figure 10, the details of the external delta arriving at the CA Agent are:

(20A, 10B, 5C)

A request to do the work is sent out to all WPC Agents

10 (20A, 10B, 5C)?

Offers are returned by the WPC Agents

(x1A, x2B, x3C) @ U from WPC1 Agent

(y1A, y2B, y3C) @ V from WPC2 Agent

15 (z1A, z2B, z3C) @ W from WPC3 Agent

The cost factor is calculated:

U . | (20 - x1)A + (10 - x2)B + (5 - x3)C | from WPC1 Agent

V . | (20 - y1)A + (10 - y2)B + (5 - y3)C | from WPC2 Agent - all the

20 work but not the cheapest

W . | (20 - z1)A + (10 - z2)B + (5 - z3)C | from WPC3 Agent

Assuming y1=20, y2=10 and y3=5 (an exact match from WPC2 Agent but not at the lowest price) the next narrowcast messages (to all except WPC2 Agent)

25 are:

| ( (20 - x1)A + (10 - x2)B + (5 - x3)C ) | <= | (V - U) |

| ( (20 - z1)A + (10 - z2)B + (5 - z3)C ) | <= | (V - W) |

where the other WPC Agents are requested to bid for the difference between the WPC2 Agent bid (an exact match but not the lowest price) and the WPC1 Agent

30 bid (the cheapest price but not an exact match).

Assume the reply from WPC2 Agent to the first narrowcast message gives a deficit in work for the right price then a narrowcast message is sent out (to WPC3 Agent in this case) for a bid that covers the difference in work required:

and work tendered for so far. From all this received information the CA Agent can generate the total cost to itself for placing the work.

Referring to Figure 9, the second scenario will involve one of the WPC Agents requesting that its workload be changed. This would occur if, for example,

- 5 the WPC Agent was notified that its WPC's resources had been reduced in some way. It is envisaged that when the CA Agent receives such a request from a WPC Agent, it deals with it in a similar way to if it had received an external delta, i.e. a process similar to the one described above is enacted. The one difference is that the first broadcast message is not sent to all WPC Agents as above but is sent to
- 10 all WPC Agents EXCEPT the one that raised the internal delta in the first place.

WPC2 Agent generates a request to reduce its type B workload:

(0A, -5B, 0C)

- 15 The CA Agent reverses the polarity of any non-zero rates, checks its residue queues and sends a narrowcast message to the other two WPC Agents:

(0A, 5B, 0C)?

As before the WPC Agents return bids for the additional work and the process

- 20 continues as before:

(0A, 5B, 0C) @ X from WPC1 Agent.

(0A, 5B, 0C) @ Y from WPC3 Agent

If the returned bids are not acceptable then the contents of the delta are added to

- 25 the residue queue for allocation at a later date.

(As before, the delta has been simplified for clarity both in the text and in Figure 9).

#### Preferred Search Options

30

Search algorithms are employed to find one or more candidate solutions to the problem of re-distributing work categories. The CA builds its distribution

plan to satisfy a given delta by inviting bids from the WPCs and evaluating the responses.

The strategy implemented is for the CA to initially broadcast an invitation to bid for the entire delta, but subsequent invitations (to bid) contain a partial delta, and are narrowcast.

The choice of which partial deltas to narrowcast to which WPCs will influence the speed at which a solution is reached, and the relative quality of that solution. It is preferred that these choices be guided at each step, by examining the responses received and proceeding with the 'best' outcome (however that is defined). Any WPC that contributed to the best outcome is removed from the list of WPCs to narrowcast the next partial delta to. This procedure is repeated until one of the following conditions is met:

- 10 a) All WPCs are eliminated;
- b) There is no residue of work;

15 c) The search times out.

Even with guided choice, there are a number of decisions to be made:

- \* How is the 'best' outcome determined at each step?
- \* How many solutions should be generated?
- 20 \* How should any residues be handled?

It is proposed that the responses from the WPC Agents are evaluated as follows:

- i) For each work category, calculate the difference between the quantity requested, and the quantity offered;
- 25 ii) Multiply each difference term by the offered price for that work category;
- iii) Multiply each difference term by the defect coefficient (derived from the quality measure) for that category;
- iv) Multiply each difference term by the CA's (inverse) priority coefficient for that
- 30 work category;
- v) Sum all the modified difference terms, and take the modulus of the result.

This single term gives the 'cost' of each response, as seen by the CA. The best response is the one with the lowest cost (with an exact match having cost = zero), and it is this response that is used as the basis of the next partial delta.

5. The overall cost of a particular solution is given by the sum of the costs of all the accepted responses (N.B. price is just one of a number of contributing factors), up to the point that condition a), b) or c) is met.

Many other search strategies are possible, but this one is bound to terminate, and will produce solutions in quadratic, rather than factorial, time. In 10 case of identical results some policy rule could be implemented to select the most appropriate.

Whenever terminal condition a) is encountered, there may be a residue of work to deal with. Although this is assumed to be positive (i.e. some work remains unplaced), there are conditions in which a negative residue may exist (i.e. 15 the CA has committed to placing more work than is currently available for distribution). This situation could arise, for example, where a WPC would be obliged to employ extra resources in the short term to meet the additional demand, but cannot exactly match the demand. It chooses to bid for more work than was offered to it (as it deems the financial cost of the overbid to be 20 marginal).

In either case, the CA Agent is responsible for recording any residues, and attempting to eradicate them as part of the process of handling subsequent deltas that it receives.

Again, choices arise - this time over how the CA manages these residues. 25 It can record them automatically, or it can seek confirmation from the User. Once recorded, subsequent management of the residues can either be automatic, or on an advisory basis. Automatic management strategies can be tempered by setting thresholds, e.g. the User could be advised when the total number of excess/deficit items exceeds X% of the WMC's 'normal' work capacity.

SUMMARY

Embodiments of the present invention show several innovative aspects.

These include for instance:

- 5 the use of at least two categories of agent, one category providing a quasi-centralised control of workload distribution;
- the capability of inter-agent negotiations to relate to multiple work-types simultaneously;
- management of over and under bidding by the use of deficit queues, or some like
- 10 record, for subsequent allocation of the relevant workload and/or, potentially, for subsequent renegotiation of available resources; and
- distribution of work according to class or type rather than by individual work items;
- response of the agent-based system in substantially real time to incoming data
- 15 from the real environment, rather than via a planning and scheduling capability.

Thus, to summarise, the present invention uses a multistage signalling process to obtain quotes for different combinations of the different resources.

This might seem simply to duplicate calculation and use valuable computing and signalling resources

- 20 In fact it would do so if the relations between volume of work and price for the different resources were linear. In this case, a single program could simply calculate all possible variations of workflow.

However, in many situations they are far from linear and accordingly, by providing two layers of agents to negotiate, with the second layer (the WPCAs)

- 25 aware of the actual status and pricing at their respective resources, non-linear behaviour can be handled.

Additionally, by providing multistage signalling, in which different combinations of quantity and price from different agents are modelled, allocations which use these nonlinearities in the supply/price curves for each resource can be

- 30 tested and the best selected.

Finally, by maintaining a baseline solution, higher cost allocations can speedily be rejected.

The invention has been described for allocation of varying workflows (i.e. rates of work) and is particularly useful for that since the long term agreements in place reduce the volume of signalling required to occasions where the rate changes rather than to each occasion when new work arrives.

5 However, it can also in principle be used for allocation of batches of work, tasks or resources rather than rates of doing them.

It will be apparent that the invention is equally suitable to, for example, the supply of electricity from multiple power stations each having a different price/power (i.e. rate of doing work) capacity; in this case, a WPCA may be 10 provided at each generator station and a CA agent at the central electricity generating headquarters for a region of a country.

It will be understood that the above described process for performing several different rounds of negotiation involves the CA agent being able to put the WPC agent "on hold", and to evaluate further bids from that agent without 15 abandoning the possibility of accepting an earlier offer from that agent. Whilst this could be applicable in trading environments (such as stocks or securities dealing) it is particularly suitable for agent-controlled resource allocation in which all agents form part of a single system, or (more generally) the CA agents are not in competition for the services of the WPC agents, so that the WPC agents have 20 no economic reason for not going "on hold" (as they might have worth a servicing competing CA agents). Accordingly, such uses of the invention are particularly preferred.

Although the above described embodiments match a need for resources (for work to be done) to a plurality of resource providers, it will be apparent that 25 they could also be used to match a resource supply to a plurality of resource users in a manner clear to the skilled reader hereof.

It will be understood that the invention is not limited to the foregoing embodiments but encompasses variations and modification thereto which would be apparent to the skilled person. Protection is hereby sought for any and all 30 novel subject matter, and combinations thereof.

## CLAIMS

1. A resource allocation system comprising computing means for executing:
  - at least one first computer program module for determining allocation
  - 5 matching one or more of a plurality of resource supplies to a resource requirement;
  - at least two second computer program modules for monitoring the state of a corresponding one of said resource supplies and for communicating with said first program module.
- 10 2. A system according to claim 1, in which said resources comprise means for performing a task at a plurality of different rates over time.
3. A system according to claim 2, in which said first computer program module and said second modules are arranged to store records relating to rates at which respective said resource supplies will perform tasks, and said resources are allocated in accordance with said agreements until changes between the rate at which tasks need to be performed and the sum of the rates stored in the agreements occur.
- 15 20 4. A system according to claim 1, for allocating an original quantity, in which the first module is arranged to:
  - a) signal, to at least two said second modules, a first request for resource supply indicating a required quantity;
  - 25 b) receive at least one response, each specifying a resource supply quantity, from respective ones of said second modules;
  - c) select one from said responses;
  - d) add the supply quantity specified therein to a running quantity total; and
  - e) if said running quantity total is less than said desired quantity,
- 30 30 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100 105 110 115 120 125 130 135 140 145 150 155 160 165 170 175 180 185 190 195 200 205 210 215 220 225 230 235 240 245 250 255 260 265 270 275 280 285 290 295 300 305 310 315 320 325 330 335 340 345 350 355 360 365 370 375 380 385 390 395 400 405 410 415 420 425 430 435 440 445 450 455 460 465 470 475 480 485 490 495 500 505 510 515 520 525 530 535 540 545 550 555 560 565 570 575 580 585 590 595 600 605 610 615 620 625 630 635 640 645 650 655 660 665 670 675 680 685 690 695 700 705 710 715 720 725 730 735 740 745 750 755 760 765 770 775 780 785 790 795 800 805 810 815 820 825 830 835 840 845 850 855 860 865 870 875 880 885 890 895 900 905 910 915 920 925 930 935 940 945 950 955 960 965 970 975 980 985 990 995 1000 1005 1010 1015 1020 1025 1030 1035 1040 1045 1050 1055 1060 1065 1070 1075 1080 1085 1090 1095 1100 1105 1110 1115 1120 1125 1130 1135 1140 1145 1150 1155 1160 1165 1170 1175 1180 1185 1190 1195 1200 1205 1210 1215 1220 1225 1230 1235 1240 1245 1250 1255 1260 1265 1270 1275 1280 1285 1290 1295 1300 1305 1310 1315 1320 1325 1330 1335 1340 1345 1350 1355 1360 1365 1370 1375 1380 1385 1390 1395 1400 1405 1410 1415 1420 1425 1430 1435 1440 1445 1450 1455 1460 1465 1470 1475 1480 1485 1490 1495 1500 1505 1510 1515 1520 1525 1530 1535 1540 1545 1550 1555 1560 1565 1570 1575 1580 1585 1590 1595 1600 1605 1610 1615 1620 1625 1630 1635 1640 1645 1650 1655 1660 1665 1670 1675 1680 1685 1690 1695 1700 1705 1710 1715 1720 1725 1730 1735 1740 1745 1750 1755 1760 1765 1770 1775 1780 1785 1790 1795 1800 1805 1810 1815 1820 1825 1830 1835 1840 1845 1850 1855 1860 1865 1870 1875 1880 1885 1890 1895 1900 1905 1910 1915 1920 1925 1930 1935 1940 1945 1950 1955 1960 1965 1970 1975 1980 1985 1990 1995 2000 2005 2010 2015 2020 2025 2030 2035 2040 2045 2050 2055 2060 2065 2070 2075 2080 2085 2090 2095 2100 2105 2110 2115 2120 2125 2130 2135 2140 2145 2150 2155 2160 2165 2170 2175 2180 2185 2190 2195 2200 2205 2210 2215 2220 2225 2230 2235 2240 2245 2250 2255 2260 2265 2270 2275 2280 2285 2290 2295 2300 2305 2310 2315 2320 2325 2330 2335 2340 2345 2350 2355 2360 2365 2370 2375 2380 2385 2390 2395 2400 2405 2410 2415 2420 2425 2430 2435 2440 2445 2450 2455 2460 2465 2470 2475 2480 2485 2490 2495 2500 2505 2510 2515 2520 2525 2530 2535 2540 2545 2550 2555 2560 2565 2570 2575 2580 2585 2590 2595 2600 2605 2610 2615 2620 2625 2630 2635 2640 2645 2650 2655 2660 2665 2670 2675 2680 2685 2690 2695 2700 2705 2710 2715 2720 2725 2730 2735 2740 2745 2750 2755 2760 2765 2770 2775 2780 2785 2790 2795 2800 2805 2810 2815 2820 2825 2830 2835 2840 2845 2850 2855 2860 2865 2870 2875 2880 2885 2890 2895 2900 2905 2910 2915 2920 2925 2930 2935 2940 2945 2950 2955 2960 2965 2970 2975 2980 2985 2990 2995 3000 3005 3010 3015 3020 3025 3030 3035 3040 3045 3050 3055 3060 3065 3070 3075 3080 3085 3090 3095 3100 3105 3110 3115 3120 3125 3130 3135 3140 3145 3150 3155 3160 3165 3170 3175 3180 3185 3190 3195 3200 3205 3210 3215 3220 3225 3230 3235 3240 3245 3250 3255 3260 3265 3270 3275 3280 3285 3290 3295 3300 3305 3310 3315 3320 3325 3330 3335 3340 3345 3350 3355 3360 3365 3370 3375 3380 3385 3390 3395 3400 3405 3410 3415 3420 3425 3430 3435 3440 3445 3450 3455 3460 3465 3470 3475 3480 3485 3490 3495 3500 3505 3510 3515 3520 3525 3530 3535 3540 3545 3550 3555 3560 3565 3570 3575 3580 3585 3590 3595 3600 3605 3610 3615 3620 3625 3630 3635 3640 3645 3650 3655 3660 3665 3670 3675 3680 3685 3690 3695 3700 3705 3710 3715 3720 3725 3730 3735 3740 3745 3750 3755 3760 3765 3770 3775 3780 3785 3790 3795 3800 3805 3810 3815 3820 3825 3830 3835 3840 3845 3850 3855 3860 3865 3870 3875 3880 3885 3890 3895 3900 3905 3910 3915 3920 3925 3930 3935 3940 3945 3950 3955 3960 3965 3970 3975 3980 3985 3990 3995 4000 4005 4010 4015 4020 4025 4030 4035 4040 4045 4050 4055 4060 4065 4070 4075 4080 4085 4090 4095 4100 4105 4110 4115 4120 4125 4130 4135 4140 4145 4150 4155 4160 4165 4170 4175 4180 4185 4190 4195 4200 4205 4210 4215 4220 4225 4230 4235 4240 4245 4250 4255 4260 4265 4270 4275 4280 4285 4290 4295 4300 4305 4310 4315 4320 4325 4330 4335 4340 4345 4350 4355 4360 4365 4370 4375 4380 4385 4390 4395 4400 4405 4410 4415 4420 4425 4430 4435 4440 4445 4450 4455 4460 4465 4470 4475 4480 4485 4490 4495 4500 4505 4510 4515 4520 4525 4530 4535 4540 4545 4550 4555 4560 4565 4570 4575 4580 4585 4590 4595 4600 4605 4610 4615 4620 4625 4630 4635 4640 4645 4650 4655 4660 4665 4670 4675 4680 4685 4690 4695 4700 4705 4710 4715 4720 4725 4730 4735 4740 4745 4750 4755 4760 4765 4770 4775 4780 4785 4790 4795 4800 4805 4810 4815 4820 4825 4830 4835 4840 4845 4850 4855 4860 4865 4870 4875 4880 4885 4890 4895 4900 4905 4910 4915 4920 4925 4930 4935 4940 4945 4950 4955 4960 4965 4970 4975 4980 4985 4990 4995 5000 5005 5010 5015 5020 5025 5030 5035 5040 5045 5050 5055 5060 5065 5070 5075 5080 5085 5090 5095 5100 5105 5110 5115 5120 5125 5130 5135 5140 5145 5150 5155 5160 5165 5170 5175 5180 5185 5190 5195 5200 5205 5210 5215 5220 5225 5230 5235 5240 5245 5250 5255 5260 5265 5270 5275 5280 5285 5290 5295 5300 5305 5310 5315 5320 5325 5330 5335 5340 5345 5350 5355 5360 5365 5370 5375 5380 5385 5390 5395 5400 5405 5410 5415 5420 5425 5430 5435 5440 5445 5450 5455 5460 5465 5470 5475 5480 5485 5490 5495 5500 5505 5510 5515 5520 5525 5530 5535 5540 5545 5550 5555 5560 5565 5570 5575 5580 5585 5590 5595 5600 5605 5610 5615 5620 5625 5630 5635 5640 5645 5650 5655 5660 5665 5670 5675 5680 5685 5690 5695 5700 5705 5710 5715 5720 5725 5730 5735 5740 5745 5750 5755 5760 5765 5770 5775 5780 5785 5790 5795 5800 5805 5810 5815 5820 5825 5830 5835 5840 5845 5850 5855 5860 5865 5870 5875 5880 5885 5890 5895 5900 5905 5910 5915 5920 5925 5930 5935 5940 5945 5950 5955 5960 5965 5970 5975 5980 5985 5990 5995 6000 6005 6010 6015 6020 6025 6030 6035 6040 6045 6050 6055 6060 6065 6070 6075 6080 6085 6090 6095 6100 6105 6110 6115 6120 6125 6130 6135 6140 6145 6150 6155 6160 6165 6170 6175 6180 6185 6190 6195 6200 6205 6210 6215 6220 6225 6230 6235 6240 6245 6250 6255 6260 6265 6270 6275 6280 6285 6290 6295 6300 6305 6310 6315 6320 6325 6330 6335 6340 6345 6350 6355 6360 6365 6370 6375 6380 6385 6390 6395 6400 6405 6410 6415 6420 6425 6430 6435 6440 6445 6450 6455 6460 6465 6470 6475 6480 6485 6490 6495 6500 6505 6510 6515 6520 6525 6530 6535 6540 6545 6550 6555 6560 6565 6570 6575 6580 6585 6590 6595 6600 6605 6610 6615 6620 6625 6630 6635 6640 6645 6650 6655 6660 6665 6670 6675 6680 6685 6690 6695 6700 6705 6710 6715 6720 6725 6730 6735 6740 6745 6750 6755 6760 6765 6770 6775 6780 6785 6790 6795 6800 6805 6810 6815 6820 6825 6830 6835 6840 6845 6850 6855 6860 6865 6870 6875 6880 6885 6890 6895 6900 6905 6910 6915 6920 6925 6930 6935 6940 6945 6950 6955 6960 6965 6970 6975 6980 6985 6990 6995 7000 7005 7010 7015 7020 7025 7030 7035 7040 7045 7050 7055 7060 7065 7070 7075 7080 7085 7090 7095 7100 7105 7110 7115 7120 7125 7130 7135 7140 7145 7150 7155 7160 7165 7170 7175 7180 7185 7190 7195 7200 7205 7210 7215 7220 7225 7230 7235 7240 7245 7250 7255 7260 7265 7270 7275 7280 7285 7290 7295 7300 7305 7310 7315 7320 7325 7330 7335 7340 7345 7350 7355 7360 7365 7370 7375 7380 7385 7390 7395 7400 7405 7410 7415 7420 7425 7430 7435 7440 7445 7450 7455 7460 7465 7470 7475 7480 7485 7490 7495 7500 7505 7510 7515 7520 7525 7530 7535 7540 7545 7550 7555 7560 7565 7570 7575 7580 7585 7590 7595 7600 7605 7610 7615 7620 7625 7630 7635 7640 7645 7650 7655 7660 7665 7670 7675 7680 7685 7690 7695 7700 7705 7710 7715 7720 7725 7730 7735 7740 7745 7750 7755 7760 7765 7770 7775 7780 7785 7790 7795 7800 7805 7810 7815 7820 7825 7830 7835 7840 7845 7850 7855 7860 7865 7870 7875 7880 7885 7890 7895 7900 7905 7910 7915 7920 7925 7930 7935 7940 7945 7950 7955 7960 7965 7970 7975 7980 7985 7990 7995 8000 8005 8010 8015 8020 8025 8030 8035 8040 8045 8050 8055 8060 8065 8070 8075 8080 8085 8090 8095 8100 8105 8110 8115 8120 8125 8130 8135 8140 8145 8150 8155 8160 8165 8170 8175 8180 8185 8190 8195 8200 8205 8210 8215 8220 8225 8230 8235 8240 8245 8250 8255 8260 8265 8270 8275 8280 8285 8290 8295 8300 8305 8310 8315 8320 8325 8330 8335 8340 8345 8350 8355 8360 8365 8370 8375 8380 8385 8390 8395 8400 8405 8410 8415 8420 8425 8430 8435 8440 8445 8450 8455 8460 8465 8470 8475 8480 8485 8490 8495 8500 8505 8510 8515 8520 8525 8530 8535 8540 8545 8550 8555 8560 8565 8570 8575 8580 8585 8590 8595 8600 8605 8610 8615 8620 8625 8630 8635 8640 8645 8650 8655 8660 8665 8670 8675 8680 8685 8690 8695 8700 8705 8710 8715 8720 8725 8730 8735 8740 8745 8750 8755 8760 8765 8770 8775 8780 8785 8790 8795 8800 8805 8810 8815 8820 8825 8830 8835 8840 8845 8850 8855 8860 8865 8870 8875 8880 8885 8890 8895 8900 8905 8910 8915 8920 8925 8930 8935 8940 8945 8950 8955 8960 8965 8970 8975 8980 8985 8990 8995 9000 9005 9010 9015 9020 9025 9030 9035 9040 9045 9050 9055 9060 9065 9070 9075 9080 9085 9090 9095 9100 9105 9110 9115 9120 9125 9130 9135 9140 9145 9150 9155 9160 9165 9170 9175 9180 9185 9190 9195 9200 9205 9210 9215 9220 9225 9230 9235 9240 9245 9250 9255 9260 9265 9270 9275 9280 9285 9290 9295 9300 9305 9310 9315 9320 9325 9330 9335 9340 9345 9350 9355 9360 9365 9370 9375 9380 9385 9390 9395 9400 9405 9410 9415 9420 9425 9430 9435 9440 9445 9450 9455 9460 9465 9470 9475 9480 9485 9490 9495 9500 9505 9510 9515 9520 9525 9530 9535 9540 9545 9550 9555 9560 9565 9570 9575 9580 9585 9590 9595 9600 9605 9610 9615 9620 9625 9630 9635 9640 9645 9650 9655 9660 9665 9670 9675 9680 9685 9690 9695 9700 9705 9710 9715 9720 9725 9730 9735 9740 9745 9750 9755 9760 9765 9770 9775 9780 9785 9790 9795 9800 9805 9810 9815 9820 9825 9830 9835 9840 9845 9850 9855 9860 9865 9870 9875 9880 9885 9890 9895 9900 9905 9910 9915 9920 9925 9930 9935 9940 9945 9950 9955 9960 9965 9970 9975 9980 9985 9990 9995 10000 10005 10010 10015 10020 10025 10030 10035 10040 10045 10050 10055 10060 10065 10070 10075 10080 10085 10090 10095 10100 10105 10110 10115 10120 10125 10130 10135 10140 10145 10150 10155 10160 10165 10170 10175 10180 10185 10190 10195 10200 10205 10210 10215 10220 10225 10230 10235 10240 10245 10250 10255 10260 10265 10270 10275 10280 10285 10290 10295 10300 10305 10310 10315 10320 10325 10330 10335 10340 10345 10350 10355 10360 10365 10370 10375 10380 10385 10390 10395 10400 10405 10410 10415 10420 10425 10430 10435 10440 10445 10450 10455 10460 10465 10470 10475 10480 10485 10490 10495 10500 10505 10510 10515 10520 10525 10530 10535 10540 10545 10550 10555 10560 10565 10570 10575 10580 10585 10590 10595 10600 10605 10610 10615 10620 10625 10630 10635 10640 10645 10650 10655 10660 10665 10670 10675 10680 10685 10690 10695 10700 10705 10710 10715 10720 10725 10730 10735 10740 10745 10750 10755 10760 10765 10770 10775 10780 10785 10790 10795 10800 10805 10810 10815 10820 10825 10830 10835 10840 10845 10850 10855 10860 10865 10870 10875 10880 10885 10890 10895 109

5. A system according to any preceding claim, in which the first module is arranged to determine a first possible allocation between resources corresponding to respective second modules, and then to determine at least one second possible allocation, and to choose one of said possible allocations.
6. A system according to claim 5 when appended to claim 4, in which the first allocation is an allocation to the resource, if any, for which the amount signalled by its respective second module exactly matches the original amount.
- 10 7. A system according to any preceding claim, in which each second module is arranged to signal a price to said first, and said first is arranged to determine said allocation based on at least one factor including said price.
- 15 8. A system according to claim 7 when appended to claim 5, in which the first module is arranged to:
  - a) store a baseline price derived from that signalled by a first of said second modules, said first being that which was selected for said first possible allocation;
  - 20 b) select another of said second modules which responded at step b) of claim 4;
  - c) perform steps d) to g) of claim 4, to derive said at least one second possible allocation.
- 25 9. A system according to claim 8, in which said first module is arranged to; form a running price total corresponding to the sum of the prices signalled in those responses for which the quantities form the running quantity total.
10. A system according to claim 9, in which said first module is arranged to;  
30 replace said baseline price with a running price total for a second possible allocation which is lower than said baseline price.
11. A system according to claim 9, in which said first module is arranged to;

cease to derive a second possible allocation when the corresponding said running price total exceeds said baseline price.

12. A system according to any of claims 8 to 11, in which said baseline price is derived jointly from the price signalled by a said second module and at least one other factor relating to the resource with which that second module is associated.

13. A system according to any preceding claim, in which said second modules are arranged to signal to said first to indicate a variation on their resource supply capacity.

14. A system according to claim 13 in which said first computer program is arranged, in response, to varying the allocation.

15. The system of claim 14 when appended to claim 4 in which the first module is arranged to perform the process of claim 4 to vary said allocation.

16. A system according to any preceding claim, wherein said resources comprise telecommunications channels.

17. A system according to any preceding claim, wherein said modules comprise software agents.

18. A method of resource allocation comprising the steps of:  
25 signalling a resource requirement quantity to a plurality of resource suppliers;

receiving replies from the resource suppliers which specify different quantities and prices;

temporarily selecting a first of said replies;

30 temporarily selecting a second of said replies from a second of said resource suppliers;

signalling to resource suppliers other than said second for supply of the different between said second and said original quantity; and.

selecting one of said temporary selections as said resource allocation.

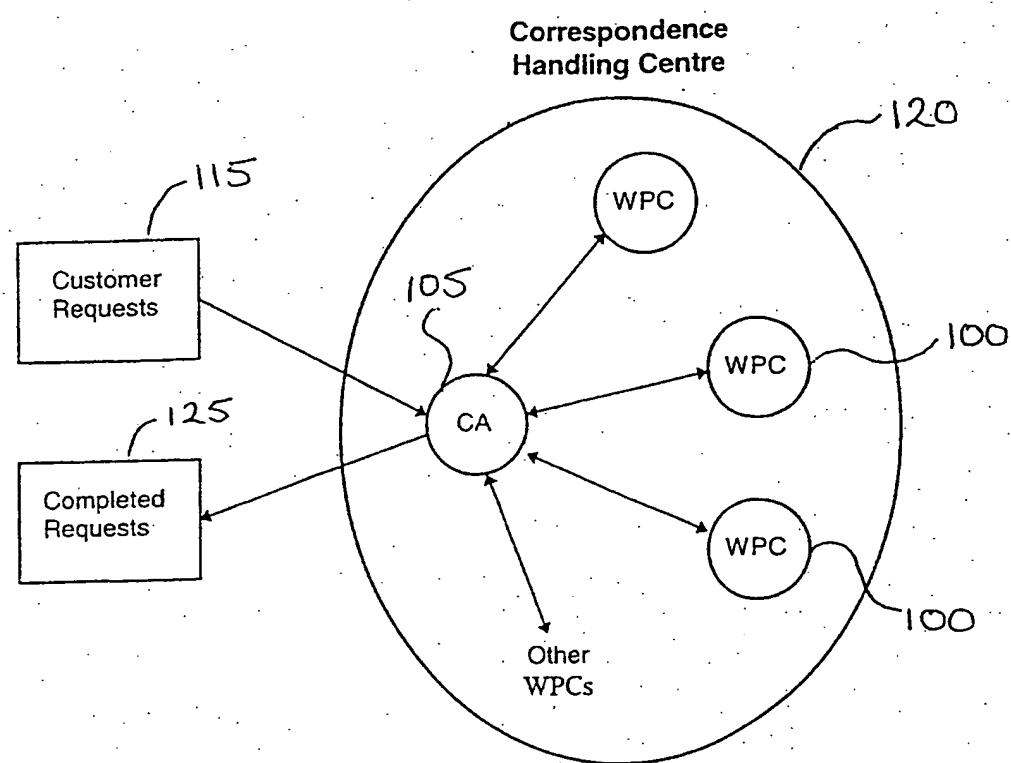
19. A workload management system for use in controlling resource allocation for tasks amongst a plurality of resources for performing the tasks, the system comprising at least one computer controlled by set of software modules, the set being provided with:

- i) at least one workload input, for receiving data relating to workload;
- ii) at least one resource-data input, for receiving resource-formulated data relating to resource availability;
- 10 iii) communication means for inter-module communication;
- iv) data storage means which stores, in use:
  - a) data representing at least one set of conditions for task performance together with identifiers for at least two of the software modules;
  - b) data representing an allocation of said tasks amongst said plurality of resources for performing the tasks; and
  - 15 c) data representing a collaborative protocol for determining collaboration between the software modules

wherein one or more administrative software modules, selected from the 20 set of software modules, is provided with said workload input, a plurality of resource-related software modules from the set are each provided with a resource-data input, and the administrative software module(s) control(s) workload management amongst said resource-related software modules.

1/15

FIG. 1



2/15

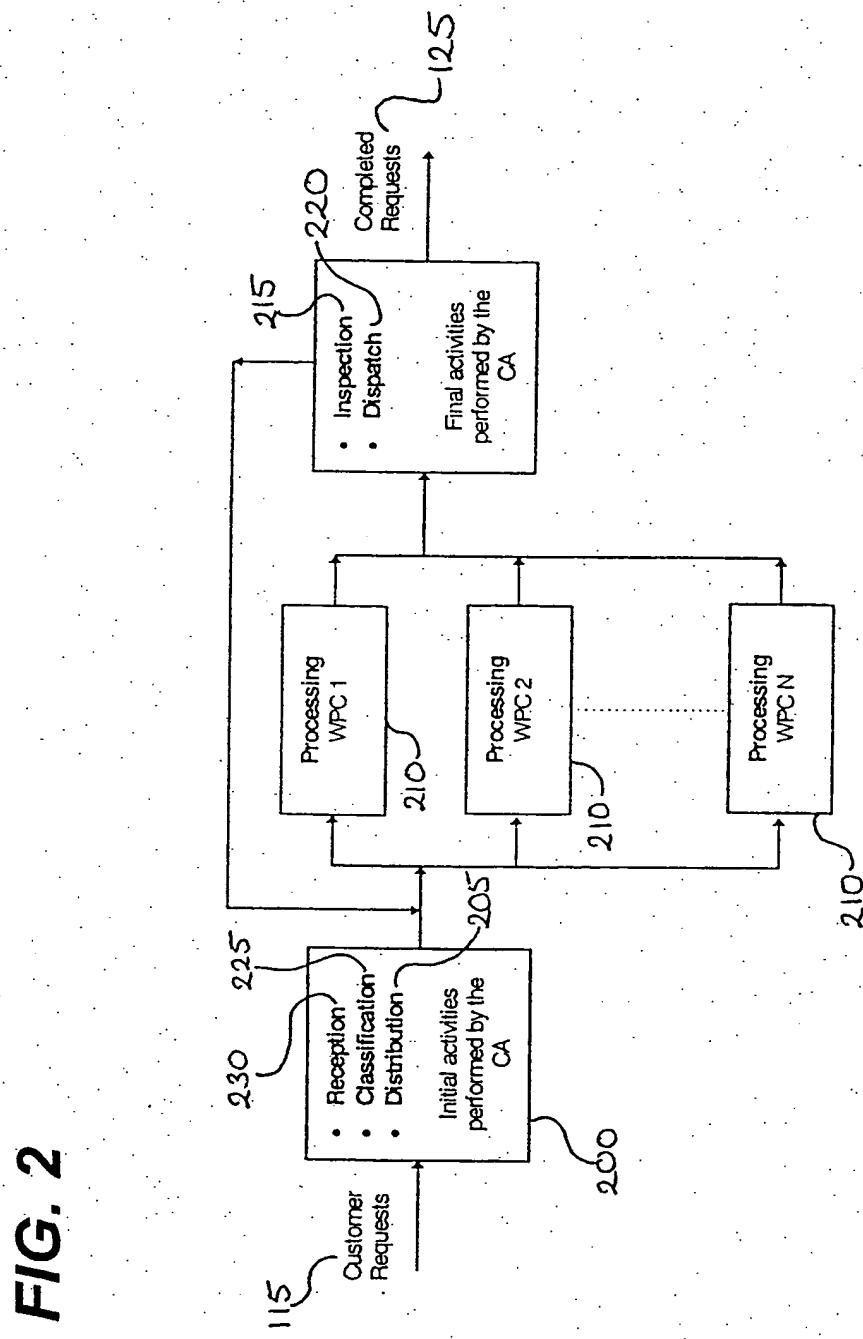
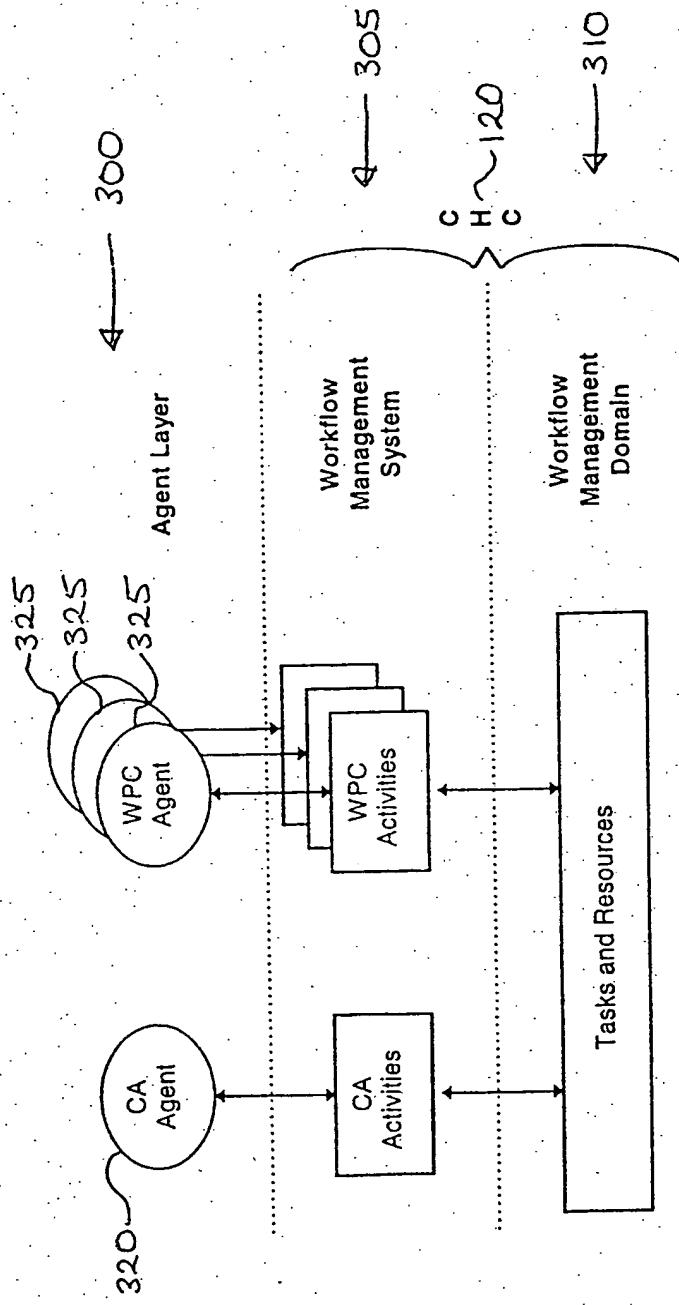


FIG. 2

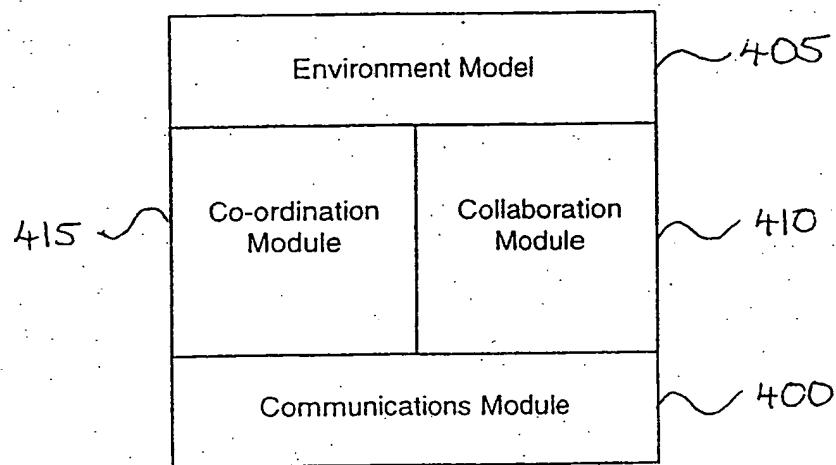
3/15

FIG. 3



4/15

FIG. 4

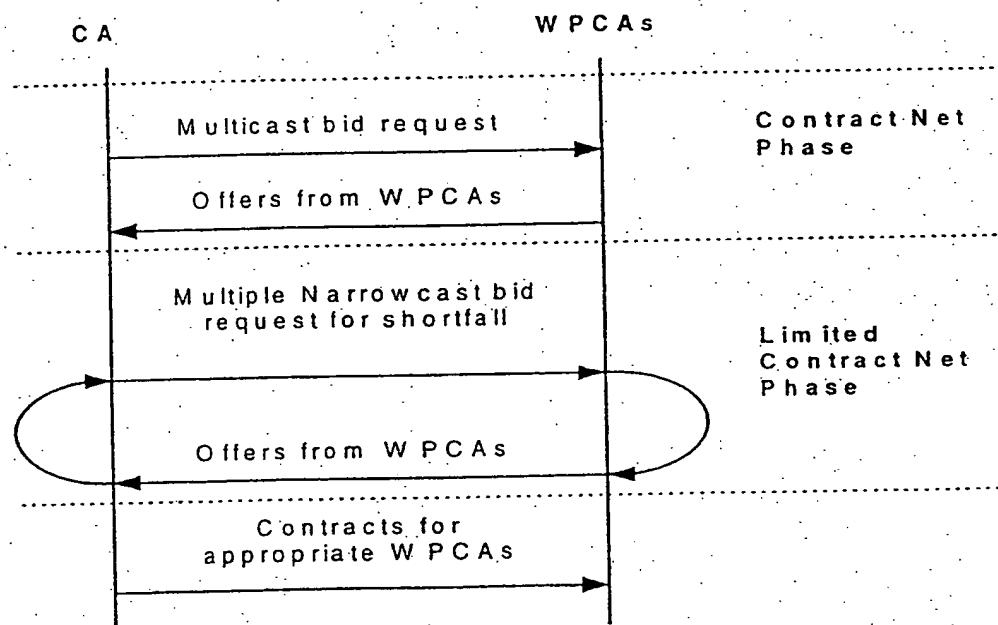


5/15

FIG. 5

Workflow Agents		CHC Model	
CA Agent		WPC Agent	Workflow Management System
Frontware (Clients)	Control GUI - JAVA	Control GUI - JAVA	Workflow Admin. Tools
Middleware (Agent-WMs)	Workflow ORB - CORBA 2 compliant C++ server with JAVA clients		
Middleware (Agent-Agent)	Agent Communications ORB - JAVA		
Backware (Servers)	Workflow Agent Architecture - JAVA	Workflow Agent Architecture - JAVA	Proprietary Workflow product

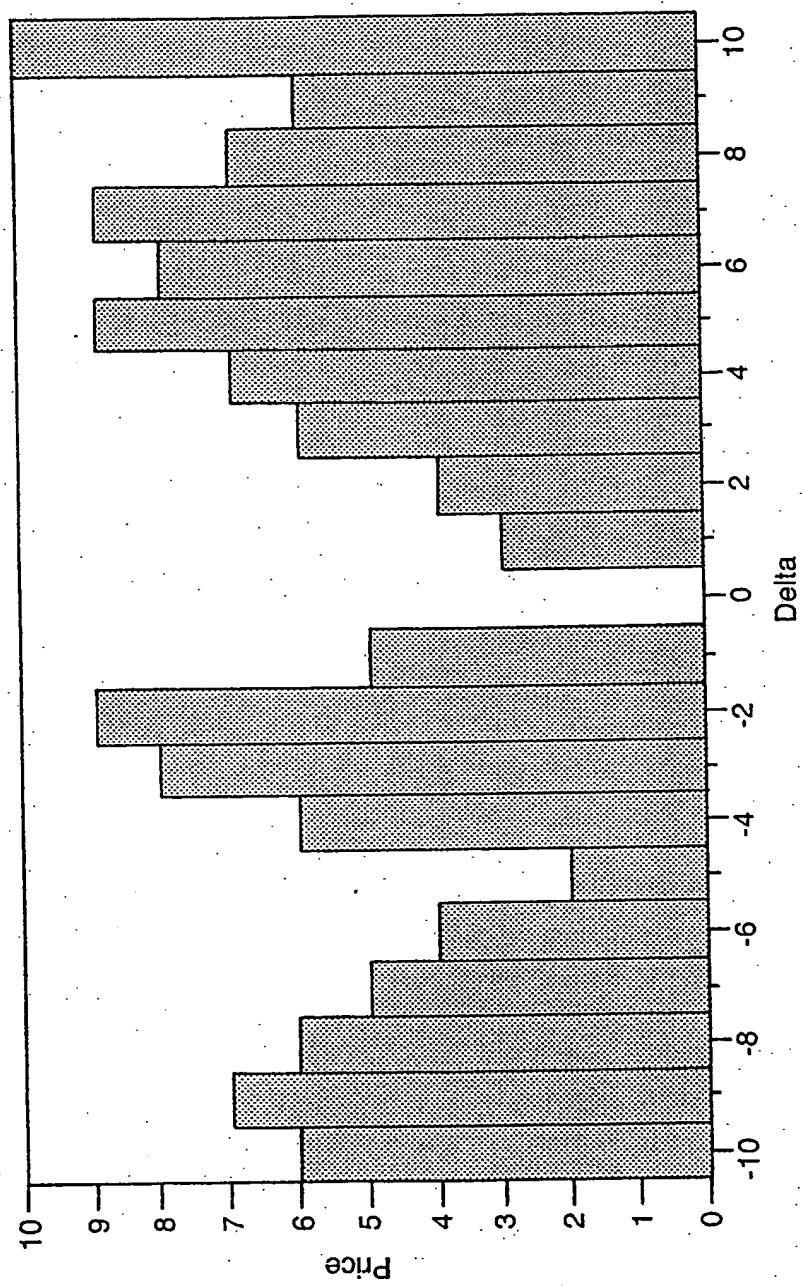
6/15

**FIG. 6**

7/15

Fig. 7.

Price profile (work category B)



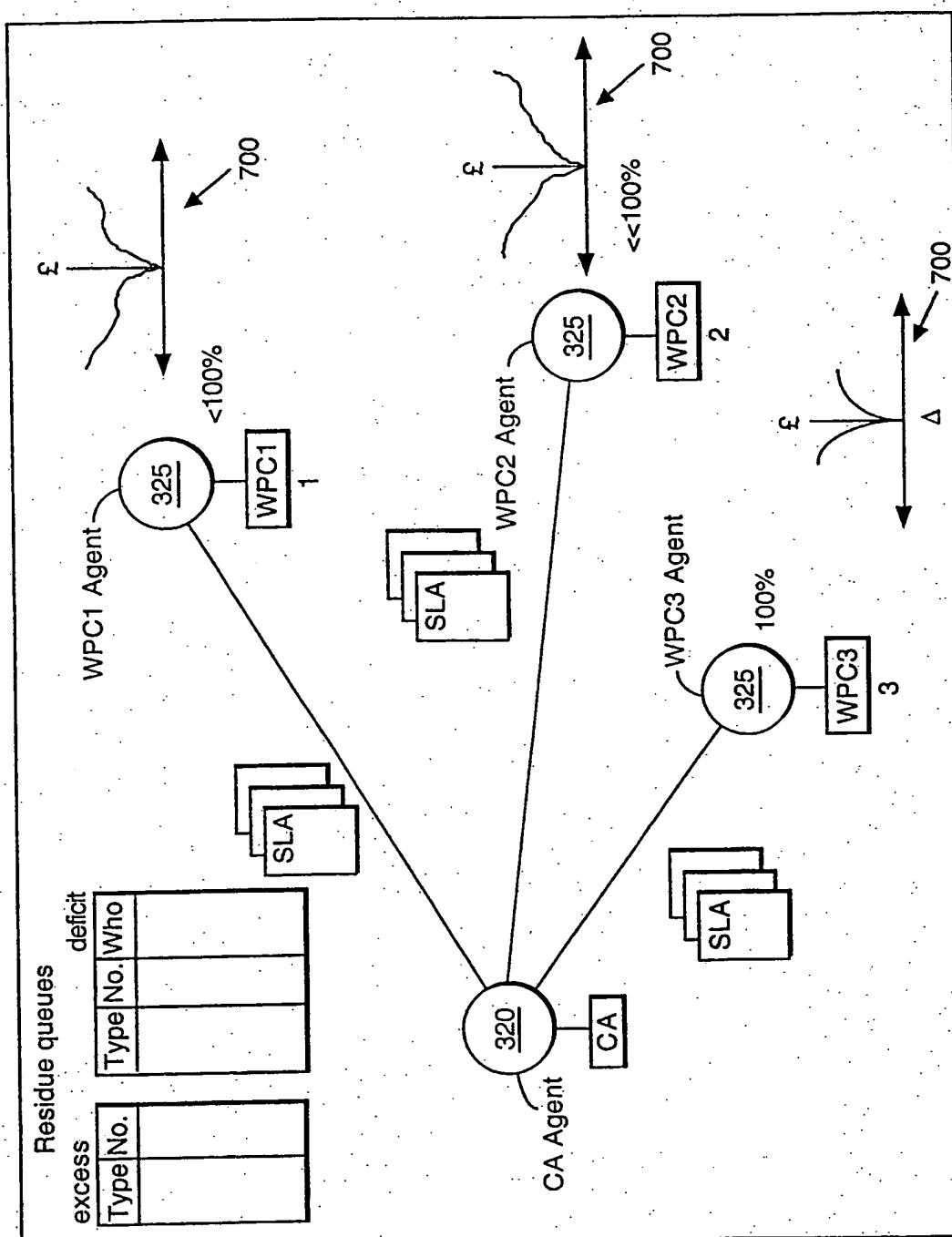


Fig.8.

SUBSTITUTE SHEET (RULE 26)

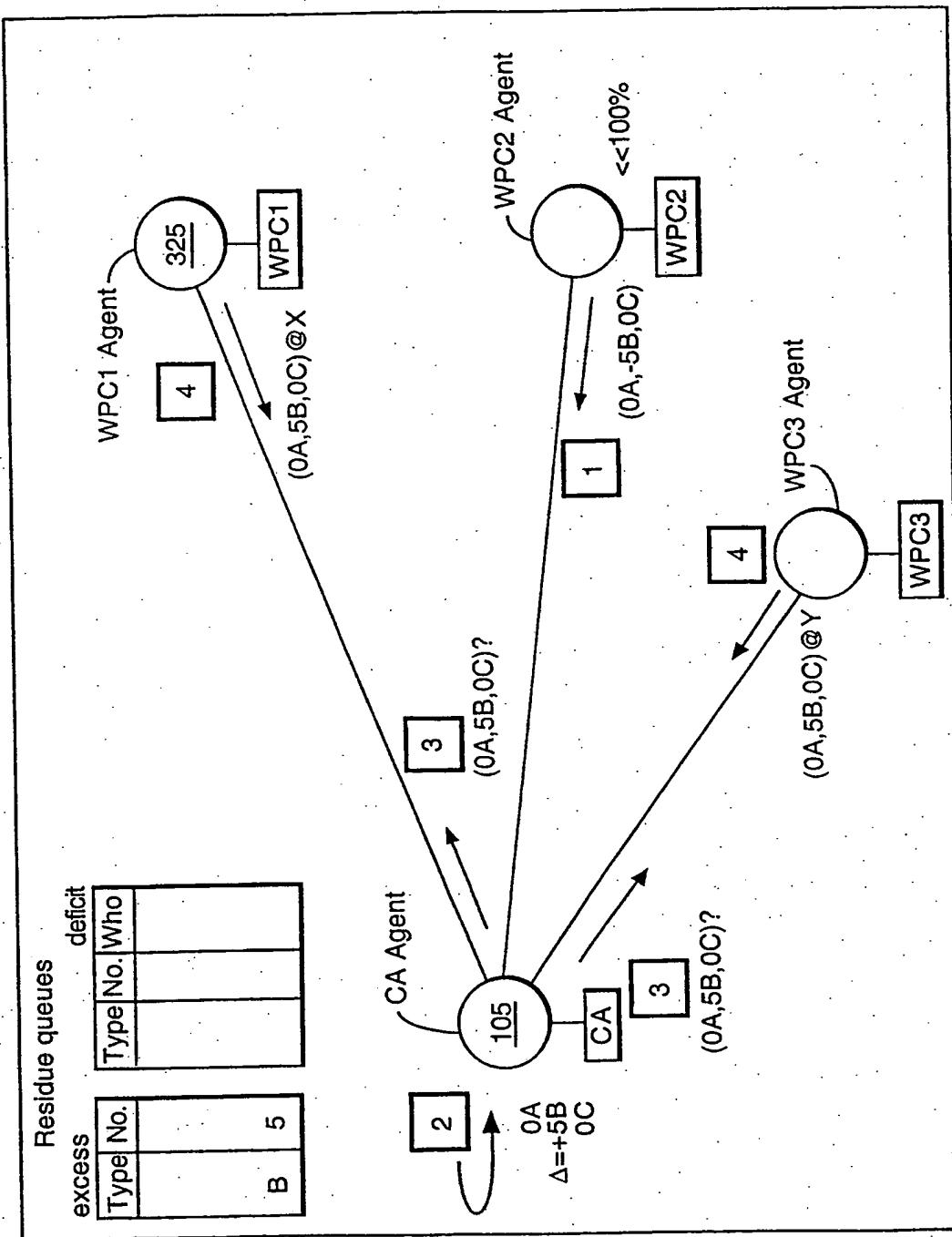


Fig.9.

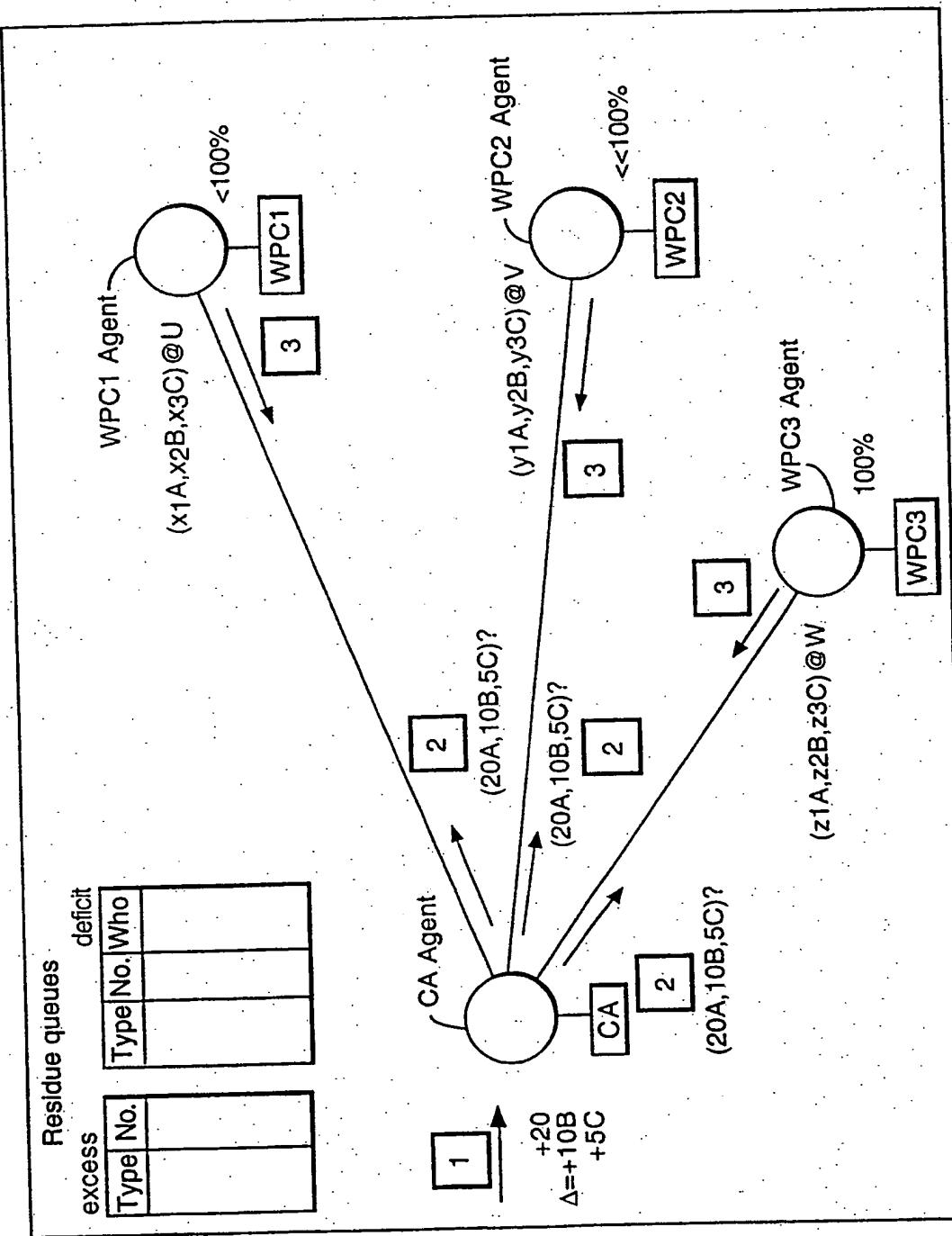


Fig. 10.

11/15

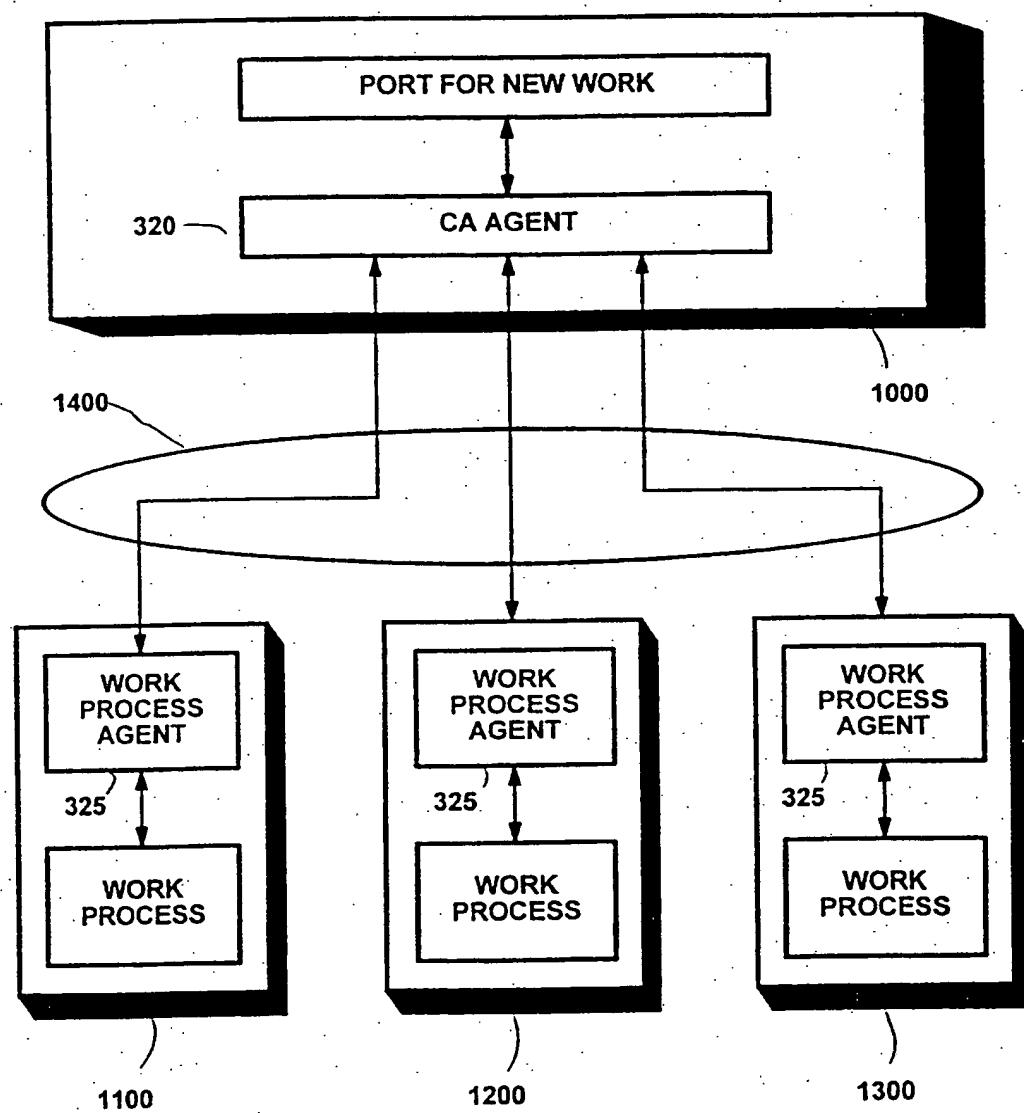


FIG. 11

SUBSTITUTE SHEET (RULE 26)

12/15

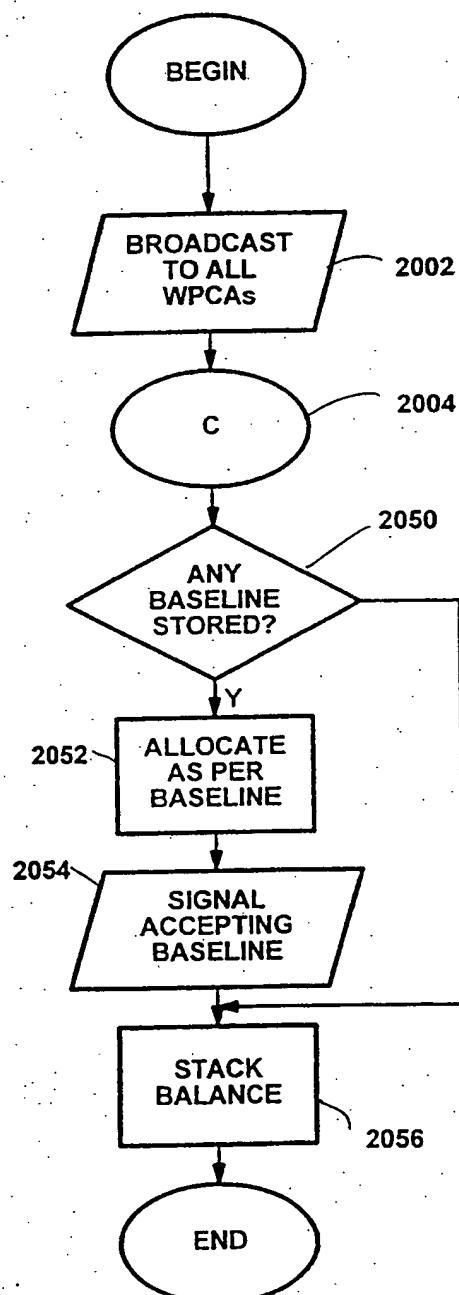


FIG. 12a

SUBSTITUTE SHEET (RULE 26)

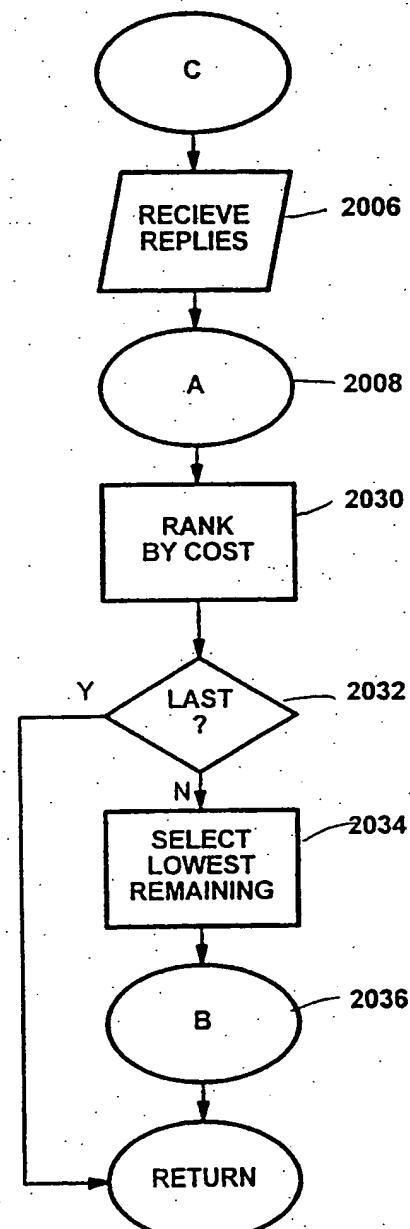


FIG. 12b

13/15

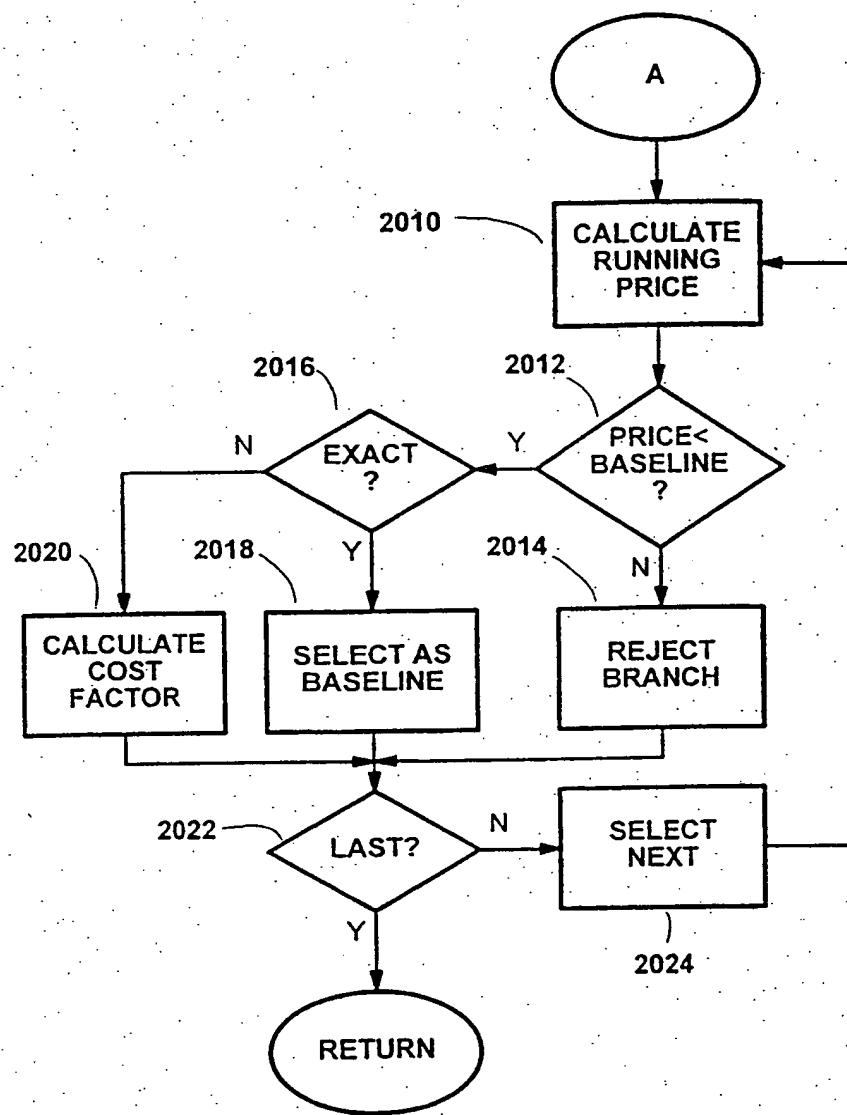


FIG. 12c

14/15

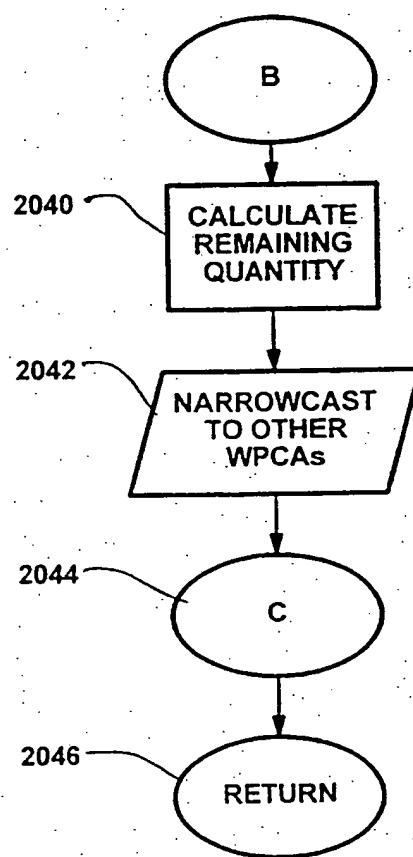


FIG. 12d

15/15

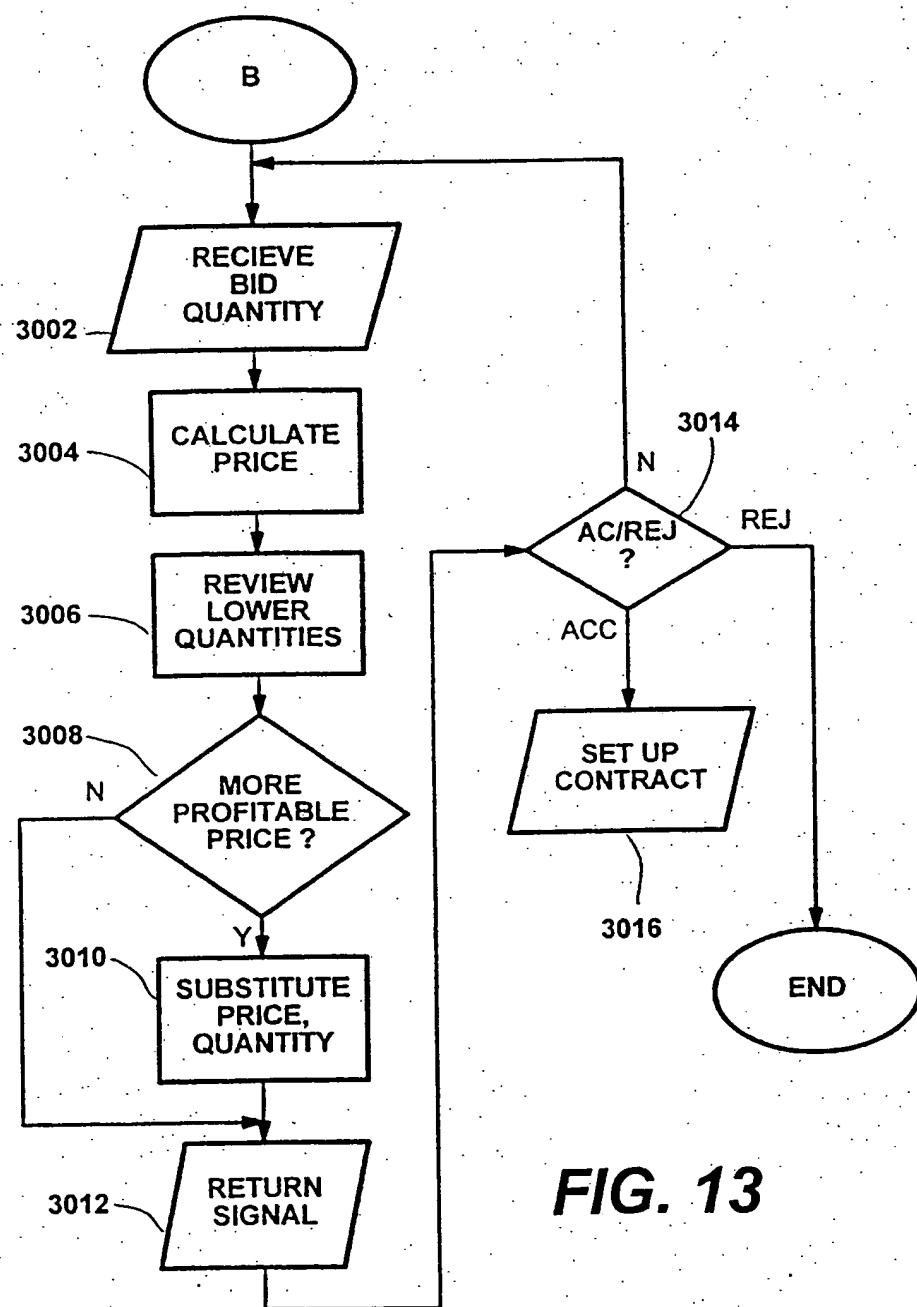


FIG. 13

SUBSTITUTE SHEET (RULE 26)

**INTERNATIONAL SEARCH REPORT**

Internatinal Application No

PCT/GB 98/02944

**A. CLASSIFICATION OF SUBJECT MATTER**  
IPC 6 G06F9/46 G06F17/60

According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)  
IPC 6 G06F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	CHAVEZ A ET AL: "Challenger: a multi-agent system for distributed resource allocation" PROCEEDINGS OF THE FIRST INTERNATIONAL CONFERENCE ON AUTONOMOUS AGENTS, PROCEEDINGS OF 1ST INTERNATIONAL CONFERENCE ON AUTONOMOUS AGENTS, MARINA DEL REY, CA, USA, 5-8 FEB. 1997, pages 323-331, XP002092534 ISBN 0-89791-877-0, 1997, New York, NY, USA, ACM, USA	1,17
A	see page 325, left-hand column, line 16 - page 326, left-hand column, line 4 -/-	18

Further documents are listed in the continuation of box C.

Patent family members are listed in annex.

\* Special categories of cited documents :

- "A" document defining the general state of the art which is not considered to be of particular relevance
- "E" earlier document but published on or after the international filing date
- "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
- "O" document referring to an oral disclosure, use, exhibition or other means
- "P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search

8 February 1999

Date of mailing of the international search report

18/02/1999

Name and mailing address of the ISA

European Patent Office, P.B. 5818 Patentlaan 2  
NL - 2280 HV Rijswijk  
Tel. (+31-70) 340-2040, Tx. 31 651 epo nl,  
Fax: (+31-70) 340-3016

Authorized officer

Michel, T

## INTERNATIONAL SEARCH REPORT

International Application No  
PCT/GB 98/02944

## C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	RAMOS C: "A holonic approach for task scheduling in manufacturing systems" PROCEEDINGS. 1996 IEEE INTERNATIONAL CONFERENCE ON ROBOTICS AND AUTOMATION (CAT. NO.96CH35857), PROCEEDINGS OF IEEE INTERNATIONAL CONFERENCE ON ROBOTICS AND AUTOMATION, MINNEAPOLIS, MN, USA, 22-28 APRIL 1996, pages 2511-2516 vol.3, XP000772583 ISBN 0-7803-2988-0, 1996, New York, NY, USA, IEEE, USA see page 0 see paragraph 3.3 see paragraph 4	1,17
A	SANDHOLM T: "Limitations of the Vickrey auction in computational multiagent systems" ICMAS-96 PROCEEDINGS. SECOND INTERNATIONAL CONFERENCE ON MULTI-AGENT SYSTEMS, PROCEEDINGS OF ICMAS '96: 2ND INTERNATIONAL CONFERENCE ON MULTIAGENT SYSTEMS, KYOTO, JAPAN, 10-13 DEC. 1996, pages 299-306, XP002092535 1996, Menlo Park, CA, USA, AAAI Press, USA see the whole document	4,18
A	GOSCINSKI A ET AL: "RESOURCE MANAGEMENT IN LARGE DISTRIBUTED SYSTEMS" OPERATING SYSTEMS REVIEW (SIGOPS), vol. 24, no. 4, 1 October 1990, pages 7-25, XP000273166 see paragraph 2 see paragraph 3; figure 5	1,18
A	GB 2 194 086 A (HITACHI LTD) 24 February 1988 see the whole document	19
A	NWANA H S ET AL: "AN INTRODUCTION TO AGENT TECHNOLOGY" BT TECHNOLOGY JOURNAL, vol. 14, no. 4, October 1996, pages 55-67, XP000635333 see the whole document	1,19
A	WO 96 03692 A (BRITISH TELECOMM ;BUTT JOHN (GB); IRELAND PAUL STUART (GB)) 8 February 1996 see the whole document	19

**INTERNATIONAL SEARCH REPORT**

Information on patent family members.

Internat'l Application No

PCT/GB 98/02944

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
GB 2194086	A 24-02-1988	JP 2533495 B	11-09-1996
		JP 63034056 A	13-02-1988
		US 4852001 A	25-07-1989
WO 9603692	A 08-02-1996	AU 689925 B	09-04-1998
		AU 2986695 A	22-02-1996
		CA 2194766 A	08-02-1996
		EP 0772825 A	14-05-1997
		FI 970288 A	24-01-1997
		JP 10503306 T	24-03-1998
		NO 970315 A	24-01-1997
		NZ 289894 A	24-11-1997

**This Page is Inserted by IFW Indexing and Scanning  
Operations and is not part of the Official Record**

## **BEST AVAILABLE IMAGES**

Defective images within this document are accurate representations of the original documents submitted by the applicant.

Defects in the images include but are not limited to the items checked:

- BLACK BORDERS**
- IMAGE CUT OFF AT TOP, BOTTOM OR SIDES**
- FADED TEXT OR DRAWING**
- BLURRED OR ILLEGIBLE TEXT OR DRAWING**
- SKEWED/SLANTED IMAGES**
- COLOR OR BLACK AND WHITE PHOTOGRAPHS**
- GRAY SCALE DOCUMENTS**
- LINES OR MARKS ON ORIGINAL DOCUMENT**
- REFERENCE(S) OR EXHIBIT(S) SUBMITTED ARE POOR QUALITY**
- OTHER:** \_\_\_\_\_

**IMAGES ARE BEST AVAILABLE COPY.**

**As rescanning these documents will not correct the image problems checked, please do not report these problems to the IFW Image Problem Mailbox.**